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POTENTIAL BENEFITS OF A WAKE VORTEX VISUALIZATION SYSTEM

by

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March 1981

Final Report

The contents of this report reflect the views of the contractor and not necessarily the official views or policies of the Transportation Development Centre.

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17. Abstract

This study estimates the savings that could be realized with the implementation of a wake vortex visualization system through the reduction of airborne and ground delays. For the traffic forecast at Toronto International Airport in 1991 and 1996, delays both for arriving and departing aircraft are estimated by means of computer simulation. The simulation was run with application of wake turbulence separation standards and with 3 nautical mile minimum separation. The percentage of time that the 3 nautical mile separation can be allowed is computed from criteria of wind conditions relative to runway designation and statistics of wind conditions for winter and summer, morning and afternoon. The reduction in delays possible when wind conditions allow the 3 nautical mile separation is converted into dollars with aircraft direct operating costs and value of passenger time.

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17. Résumé

Cette étude évalue les économies réalisables de la mise en exécution du système de visualisation du sillage vortex en vue de réduire les retards de temps de vol et de sol. Les délais d'arrivées et de départs dans les perspectives du trafic à l'aéroport international de Toronto pour les années 1991 et 1996 ont été évalués par simulation sur ordinateur. La simulation a été conduite en tenant compte des normes du sillage de turbulence au décollement et d'un espacement minimum de 3 milles marins. Le pourcentage de temps de l'espacement minimum qui peut être toléré est calculé à partir des critères des conditions de vent en regard de la conception des pistes et selon les statistiques des conditions de vent durant l'hiver et l'été, le matin et l'après-midi. La réduction possible dans les délais lorsque les conditions de vent permettent l'espacement minimum de 3 milles marins est convertie en dollars, y incluant les coûts directs d'exploitation de l'appareil et l'économie de temps des passagers.

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SUMMARY

This study estimates the savings that could be realized if a wake vortex visualization system would enable Air Traffic Control (ATC) to reduce longitudinal separation to a minimum of 3 nautical miles between all types of aircraft. The scenario for the evaluation is Toronto International Airport (TIA) in the decade of the 1990s.

Wind conditions during which wake vortices produced by aircraft are dissipated or transported out of the flight path of following aircraft have been taken as determined by the Federal Aviation Administration (FAA) in tests of various airports including Toronto.

The prevalence of such favorable wind conditions was determined from ten year wind statistics. These statistics were then related to the current runway utilization practices at Toronto to arrive at probabilities of reduction of separation standards. This was done separately for winter and summer, morning and afternoon in connection with the variation of traffic volume.

The characteristics of the aircraft traffic with respect to aircraft types and diurnal distribution were derived from Transport Canada forecasts for 1991 and 1996. The variation over the year was estimated on the basis of statistics for a recent full year.

By discrete event simulation of a 24 hour day of traffic at different levels, delays with the current wake turbulence separation standards and with the 3 nautical mile separation were computed for the critical runway configuration operations. The reduction in airborne and ground delays possible by the lifting of the wake turbulence standards were multiplied by aircraft operating costs and passenger time values to obtain monetary benefits which might be achieved at TIA at 1980 constant dollars.

Results of the calculations show a theoretical potential benefit of $8.3 million in 1991, increasing to $33.3 million by 1996. The actual savings will, on the one hand be less due to problems in transition from one set of standards to another, and on the other hand may be higher if the general practice of operating into wind would be changed to operating with cross-wind. The dollar amounts are very sensitive to price of fuel and to value of passenger time. Savings for light aircraft are insignificant compared to those for medium and heavy aircraft and their passengers.

Savings in investment of runway construction do not appear to be possible because greater separations are necessary for a substantial percentage of the time; this is due to the prevalence of light winds which are conducive to long wake vortex life.

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1. INTRODUCTION

The Aeronautics Advisory Board (AAB) recommended that Transport Canada undertake a development program aimed at detecting the existence of wake vortices in the portions of the approach and departure flights paths where such vortices could affect following aircraft. This study is the first step taken in response to the AAB recommendation, and is jointly sponsored by the Air Administration and the Transportation Development Centre.

The separation of aircraft, administered by air traffic control to minimize the risk to aircraft following a larger wake vortex producing aircraft, causes delays to aircraft and reduces the traffic flow.

If an airport were equipped with a system that shows air traffic controllers how long the wake vortex persists in the flight path of the succeeding aircraft, the horizontal separation could be adapted, i.e. reduced, traffic flow could be increased and delays reduced or prevented.

The objective of this study is to estimate the monetary benefits that would accrue with the implementation of a wake vortex visualization system through the reduction of aircraft operating costs, passenger travel time, and possibly postponement of runway system expansion.

Toronto International Airport (TIA) was selected by Transport Canada as scenario for evaluation of such a system with air traffic as forecast by Transport Canada for 1991 and 1996.

Digital computer simulation of arrival and departure operations was chosen as the method to estimate delays with and without wake turbulence separation standards.

2. SCENARIO

Air Traffic Control of TIA has established eight modes of operation of the runway system for busy hours[1]. These compatible runway combinations are shown in Figures 2.1A and B.

Combination (d) has the greatest overall (IFR and VFR) capacity. Combination (e) has the greatest IFR only capacity. Due to prevailing westerly winds (e) has the greatest utilization. Configuration (a) is good in calm and southerly winds, (d) is good in calm and northerly winds.

When the single Runway 14/32 is in use, due to wind strength and direction, departures and arrivals have to be interleaved. Therefore the tower controller has to release a departure immediately after a landed aircraft has cleared the runway and prior to the next arrival in a well-timed procedure. This requires a 6 mile separation between successive arrivals. Wake turbulence separation is thus automatically applied, and reduction of separation as a result of dissipated wake vortex is not possible. Wake turbulence separation is not applied between an arriving and a departing aircraft and vice versa and there is no regulation covering this type of situation. Furthermore, the demand forecast assumes no facility constraint, which cannot be said of a single runway operation. Therefore, the single runway operation was eliminated for this study (Configurations (g) and (h)).

Combination (b) was used more frequently than (c), presumably because it entails shorter taxi distances. However, (c) has higher capacity and will probably be used more frequently in the future when demand is higher. For the purposes of this study combinations (c) and (e) are equal, and will give identical results in terms of capacity and separation reduction potential. Hence, the simulation of (e) will suffice for both combinations. Similarly (b) and (f) are equal for capacity calculation and separation simulation purposes. The future two parallel 14/32 runways configuration can be considered equal to (b), (c), (e) or (f).

For VFR flights the controller has great scope for avoiding wake turbulence separation by directing aircraft such that they stay above heavier aircraft and land at a

[1] During quiet hours, other traffic patterns may be used to suit the users.

FIGURE 2.1A

TORONTO INTERNATIONAL AIRPORT
COMPATIBLE RUNWAY COMBINATIONS

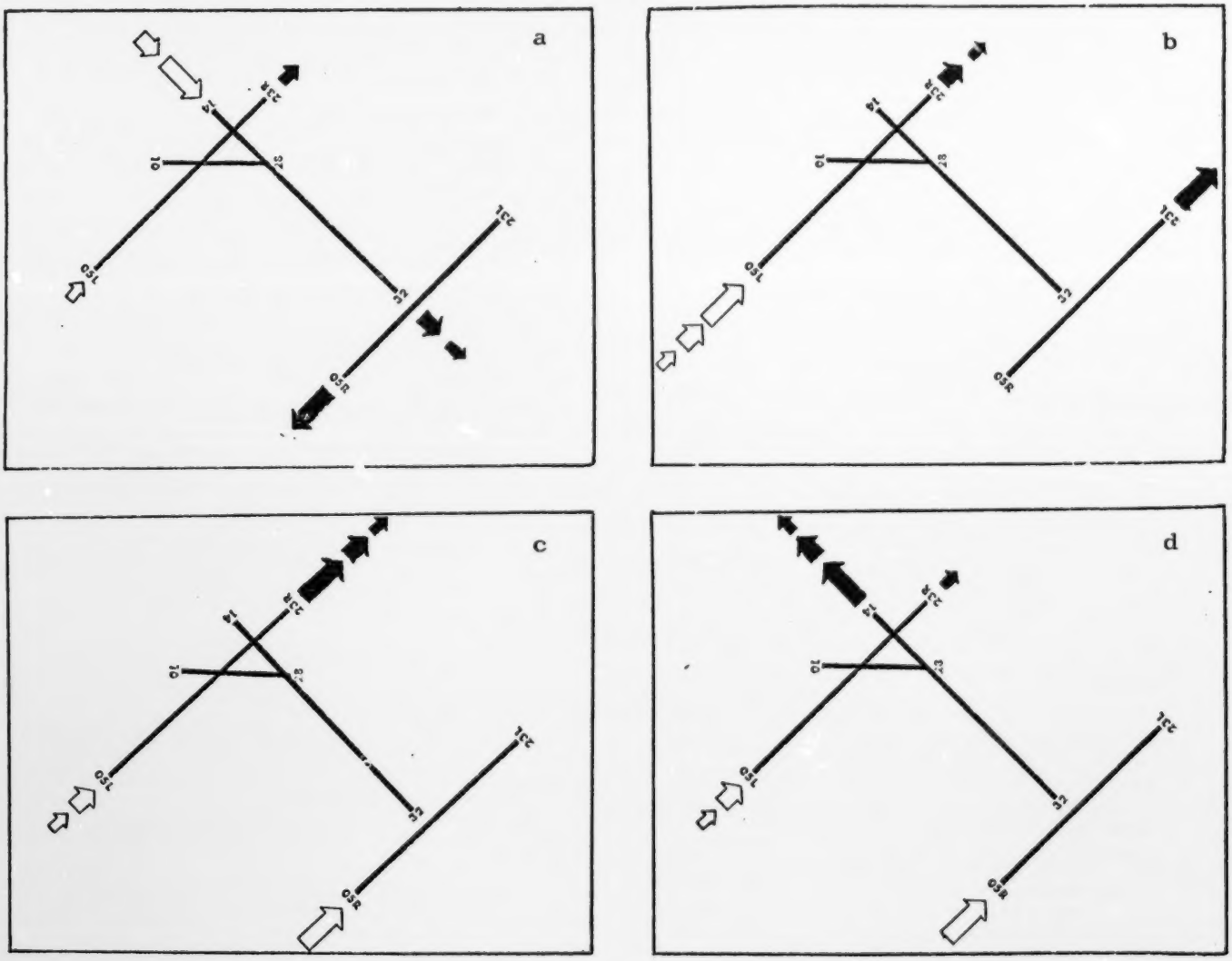
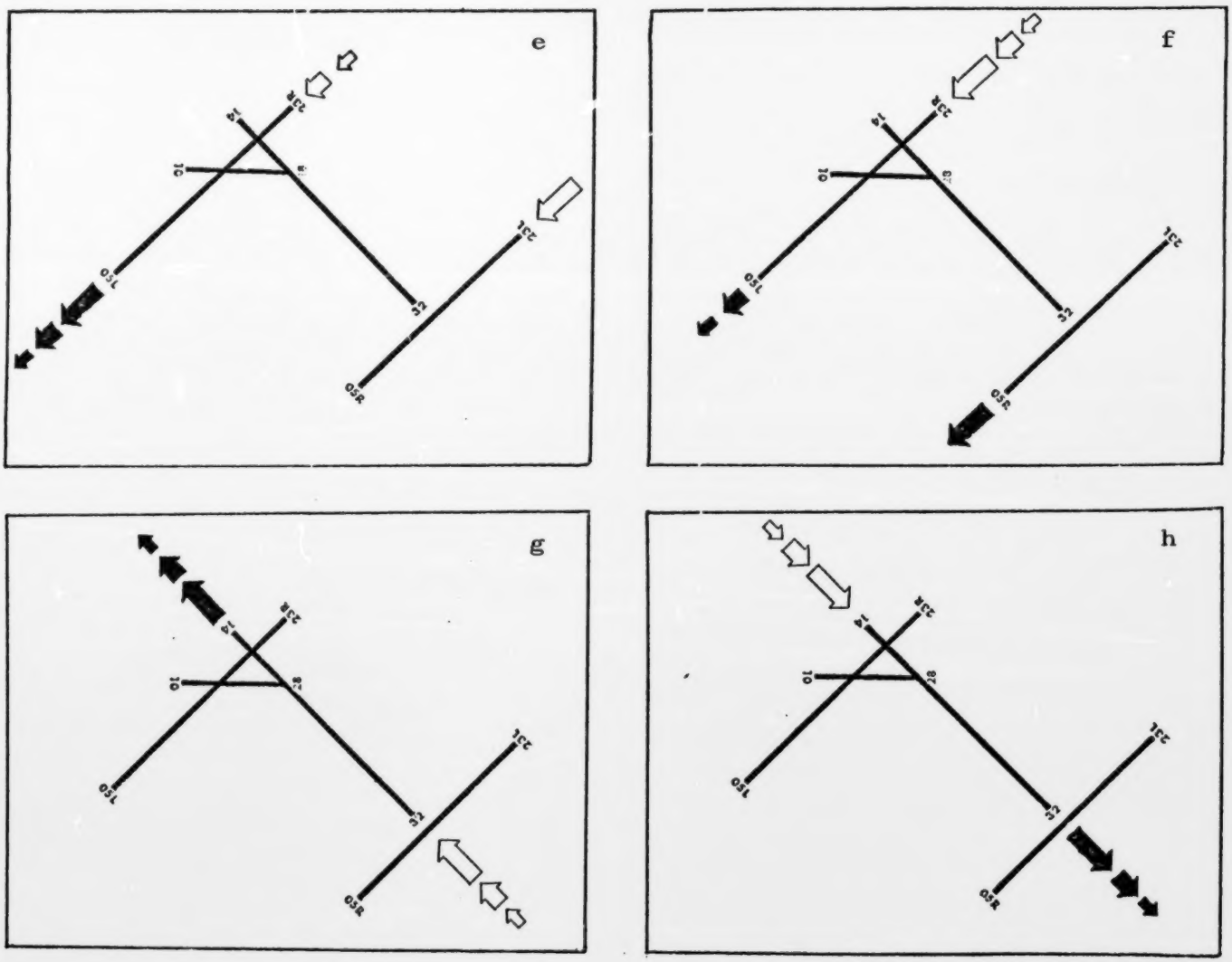


FIGURE 2.1B

TORONTO INTERNATIONAL AIRPORT
COMPATIBLE RUNWAY COMBINATIONS



LEGEND

ARRIVALS	DEPARTURES
COM IFR	COM IFR
G/A IFR	G/A IFR
G/A VFR	G/A VFR

point ahead of the heavier aircraft's touchdown or take-off far short of the heavier aircraft's lift-off. When such expediting measures are not possible, arriving light aircraft are delayed in holding patterns or circuitous routes till a bunch of heavies have been processed. Likewise on departure, light aircraft are usually the ones that are delayed for reasons of wake turbulence avoidance. Since the operational costs and the number of occupants of light aircraft are much less than those of the heavy aircraft, financial and social costs are minimized in this manner of operation.

Tabulation of arrival and departure times between 2200 and 2300 GMT on July 24, 1980 - one of the peak-days of the year - shows that frequently VFR movements are within a minute of IFR movements and other VFR flights. (Table 2.1).

Analysis of the monthly reports for March 1979 to February 1980 (Table 2.2) shows that VFR flights constitute only 14 to 20 per cent of total itinerant movements. It is probable that with increasing jet traffic the VFR flights, which are mainly by light aircraft, will be increasingly discouraged from using TIA, so that their share will be further reduced. It was, therefore, assumed justified to ignore VFR traffic in the simulation.

IFR traffic levels under Instrument Meteorological Conditions (IMC) are less than under Visual Meteorological Conditions (VMC), due to the dropping out of marginal general aviation IFR capability. Also runway conditions, thunderstorms etc. may reduce traffic. Delays under those conditions are not related to wake turbulence. Hence, the simulation will use IFR traffic levels and mix as observed under VMC.

The utilization of the eight runway configurations in 1978 and 1979 is given in Table 2.3.

TABLE 2.1

TORONTO INTERNATIONAL AIRPORT
RUNWAY UTILIZATION

July 24, 1980

23L			23R					
	ARR			ARR		DEP		
	IFR	△		IFR	VFR	IFR	VFR	△
L 101	2200	2	DC 93			2200		1
B 737	2202	2	B 737			2201		1
B 737	2204	0	BE 90			2202		0
DC 93	2204	4	PA 30				2202	0
DC 86	2208	3	C 172				2202	2
DC 86	2211	3	CV 58			2204		2
CV 58	2214	2	PA 28		2206			0
CV 58	2216	1	DC 93			2206		2
DC 93	2217	4	PA 31			2208		1
B 747	2221	2	C 172		2209			1
B 727	2223	2	DC 86			2210		2
B 707	2225	2	DC 10			2212		2
DC 93	2227	1	DC 93			2214		2
DC 93	2228	4	NG 3				2216	0
DC 93	2232	4	PA 30				2216	3
B 727	2236	2	C 182		2219			0
B 747	2238	2	DC 10			2219		1
B 737	2240	1	DC 93			2220		1
B 727	2241	2	DC 93			2221		2
L 101	2243	3	B 727			2223		1
B 737	2246	7	DC 86			2224		2
DC 93	2253	2	DC 86			2226		5
DC 86	2255	2	DC 93			2231		1
DC 86	2257	2	DH ZT		2232			2

Table 2.1 - Runway Utilization (cont'd)

23L			23R					
	ARR			ARR		DEP		
	IFR	△		IFR	VFR	IFR	VFR	△
B 727	2259	3	C 421	2234				3
B 727	2302		C 172		2237			0
			DC 86			2237		3
			DC 4		2240			0
			DC 93			2240		1
			G 2	2241				1
			BE 20			2242		3
			B 747			2245		2
			AA 5				2247	1
			C 172		2248			1
			DC 10			2249		2
			DC 10			2251		1
			PA ZT	2252				2
			B 727			2254		1
			B 737			2255		2
			DC 93			2257		1
			B 727			2258		2
			DC 86			2300		

Total Intervals - Min.		Total Intervals - Min.	
1 x 7 =	7	1 x 5 =	5
4 x 4 =	16	4 x 3 =	12
4 x 3 =	12	14 x 2 =	28
12 x 2 =	24	15 x 1 =	15
3 x 1 =	3	7 x 0 =	0
1 x 0 =	0		
Total	62	Total	60

SOURCE: Tower Records
APS Analysis

TABLE 2.2

TORONTO INTERNATIONAL AIRPORT
MONTHLY DISTRIBUTION OF TRAFFIC

DATE	TOTAL AIRCRAFT MOVEMENTS	ITINERANT MOVEMENTS	LOCAL MOVEMENTS	INSTRUMENT FLIGHT RULES	VISUAL FLIGHT RULES	PERCENT OF ANNUAL IFR MOVEMENTS
March 1979	22,630	21,653	977	17,896	3,757	8.44
April	21,810	21,179	631	16,935	4,[illegible]44	7.99
May	23,031	22,641	390	18,015	4,626	8.50
June	22,880	22,296	584	17,970	4,326	8.47
July	23,626	22,967	659	18,570	4,397	8.76
August	23,644	23,147	497	18,808	4,339	8.87
September	22,451	22,024	427	17,453	4,571	8.23
October	22,145	21,521	624	18,482	3,039	8.71
November	20,639	20,122	517	17,283	2,839	8.15
December	19,511	18,928	583	16,604	2,324	7.83
January 1980	20,892	20,312	580	17,357	2,955	8.19
February	19,950	19,545	405	16,669	2,876	7.86
Total	263,209	256,335	6,874	212,042	44,293	100.00

SOURCE: Monthly Reports on Aircraft Movements, Aviation Statistics Centre.
APS Analysis

TABLE 2.3

UTILIZATION OF RUNWAY CONFIGURATIONS - PERCENT
1978, 1979

CONFIGURATION	WINTER	SUMMER	ALL YEAR
a	12	20	16
b	6	8	7
c	4	4	4
d	14	16	15
e	32	30	31
f	12	6	9
g	12	12	12
h	4	2	3
Other	4	2	3
Total	100	100	100

SOURCE: Toronto ATC

3. METHODOLOGY

3.1 Simulation

The effect of different separation rules on arrival and departure delays is best estimated by computer simulation, in which traffic levels and mix can be varied. The simulation program used is a discrete event simulation that moves each aircraft through the steps of the arrival or departure process, obeying air traffic rules and separation standards as applied at TIA. This program is a subset of the Aviation Simulations International ASM-2 airport simulation model that has been used several times previously to simulate the operations at TIA. The subset used for this study applies only to the runways. Details of taxiing and apron operations have been omitted as not germane to the study.

The simulation is run separately for the current 4/5/6 nautical mile separation for wake turbulence and for the minimum 3 nautical mile separation. No transition from one standard to the other is simulated.

The simulation tabulates the delays that occur in sequencing aircraft landing and take-off. The results are provided in three forms:

a) summary of average delay in minutes to arrivals and departures in each hour of the day

b) number of arrivals and departures assigned to each runway along with the mean delay for arrivals and departures on that runway

c) mean delay per aircraft by wake turbulence class for each runway configuration.

3.2 Application of Wake Vortex Visualization Systems

Several systems have been developed which sense the presence of vortices in the air along the flight path. However it is impractical to have the traffic controller watch the multidimensional output of these sensors in order to decide whether to allow reduction of separation of following aircraft. Therefore the Federal Aviation Administration (FAA) is developing ground systems which will provide information to the controller on which separation standards to apply. Such systems are based on two considerations which have been derived from extensive data on vortex behavior.(1)

1) Meteorological conditions exist a large percentage of the time which cause vortices to move quickly off the flight path or decay rapidly in the approach corridor such as not to present a hazard to aircraft following on the same flight path.

2) The duration, intensity, and movement of vortices can be reliably predicted if adequate knowledge of the existing meteorological conditions and the generating aircraft's characteristics are known.

Figure 3.1 shows the probability of finding a vortex in a safety corridor of 150 feet on both sides of the extended runway centre line after an aircraft passed. The figure is a composite of data recorded at Denver, JF Kennedy and Heathrow Airports and represents the results of 35,303 aircraft. Cross-wind magnitude plays an important role in the motion of the vortices. As a result of further analysis of wind conditions on vortex life time, an ellipse could be constructed containing wind rose data in relation to residence time of vortices in the corridor. For the wake vortex advisory system developed by the FAA for O'Hare Airport, an ellipse with a semi-major axis (head-wind/tail-wind) of 12 knots and a semi-minor axis (cross-wind) of 5.5 knots was used. When the winds are within the ellipse, less than 5 per cent of the vortices will persist in the safety corridor in excess of 80 seconds (2). An 80 second period is equivalent to 3 nautical miles distance at a ground speed of 135 knots, the average approach speed of medium size aircrafts. Lighter, slower, aircraft will take more time to cover this distance. Since the adoption of this ellipse, tests have been conducted at TIA, where 5,633 take-offs were monitored. It was established that the vortices generated during take-off are stronger and therefore linger longer than those of approaching aircraft. Figure 3.2 shows the wind conditions (one minute running averages) which caused at least one of the two vortices generated by a heavy aircraft to remain in a corridor of 200 feet on both sides of the runway centre line longer than 90 seconds (3). The 400 feet wide corridor is overly safe[1)] and furthermore it is highly probable that the detected long-lived vortices were only very weak vortex remnants (3).

1) It was established by tests in Denver that 99.74 per cent of all landing aircraft were within 50 feet of the extended runway centre line at 1,500 feet from threshold (2).

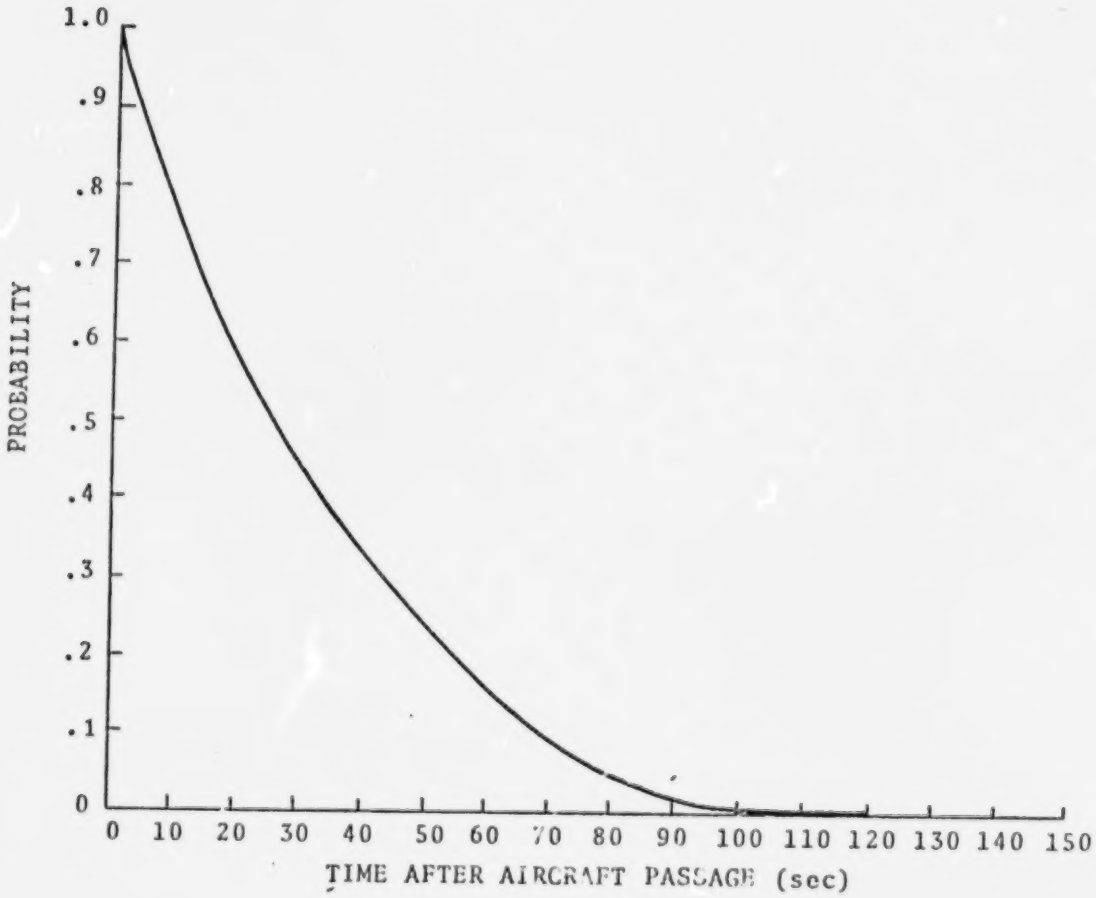


FIGURE 3.1

PROBABILITY OF FINDING A VORTEX IN THE SAFETY CORRIDOR

Nevertheless, to ensure a conservative approach, the ellipse of Figure 3.2 was adopted to indicate the area of the wind rose in which full wake turbulence separation should be maintained. When the wind vector is outside the ellipse, the minumum 3 nautical mile separation can be applied.

For the traffic to adjust to a 3 nautical mile separation pattern takes up to 10 minutes. Speed adjustment would be made on the localizer to reduce separation on final approach. Aircraft on the downwind and base legs can be directed to cut corners for this purpose, just as Visual Flight Rules (VFR) flights are allowed to do at present.

Also the change from 3 nautical miles separation to the wake turbulence separation of 4, 5 and 6 nautical miles it is estimated that about 10 minutes would lapse before traffic is normalized again. Obviously on days where the wind is constantly either inside or outside the ellipse these changeover problems do not arise.

At present it does not appear to be possible for the controller and the traffic to respond faster and more precisely to the behavior of the wake vortices, in particular on a multi runway airport, where several controllers have to co-ordinate their actions.

However in the 1990s computer ordered spacing and flow metering is expected to simplify the controller's task and make the application of a wake vortex visualization system a practicable proposition.

3.3 Meteorological Factors

At the beginning of each day[1] the selection of runway is the controller's responsibility. The selection is based on the wind direction and velocity. If the wind is suitable, the best combination is selected to move departures and arrivals in the most expeditious fashion. However, due to noise abatement regulations, a rotation is made every four hours. The new runway conbination selected, based on optimum wind conditions, must expedite traffic as efficiently as the previous combination. There are charts[2] used by the controller in determining preferential runways. These charts indicate the maximum acceptable wind speed, dependent on angle between wind and runway for landing and take-off (15 knots and 20 knots respectively). Runway selection must be

[1] 7:00 a.m. for jet traffic.

[2] ATS Directive 906 effective March 23, 1979.

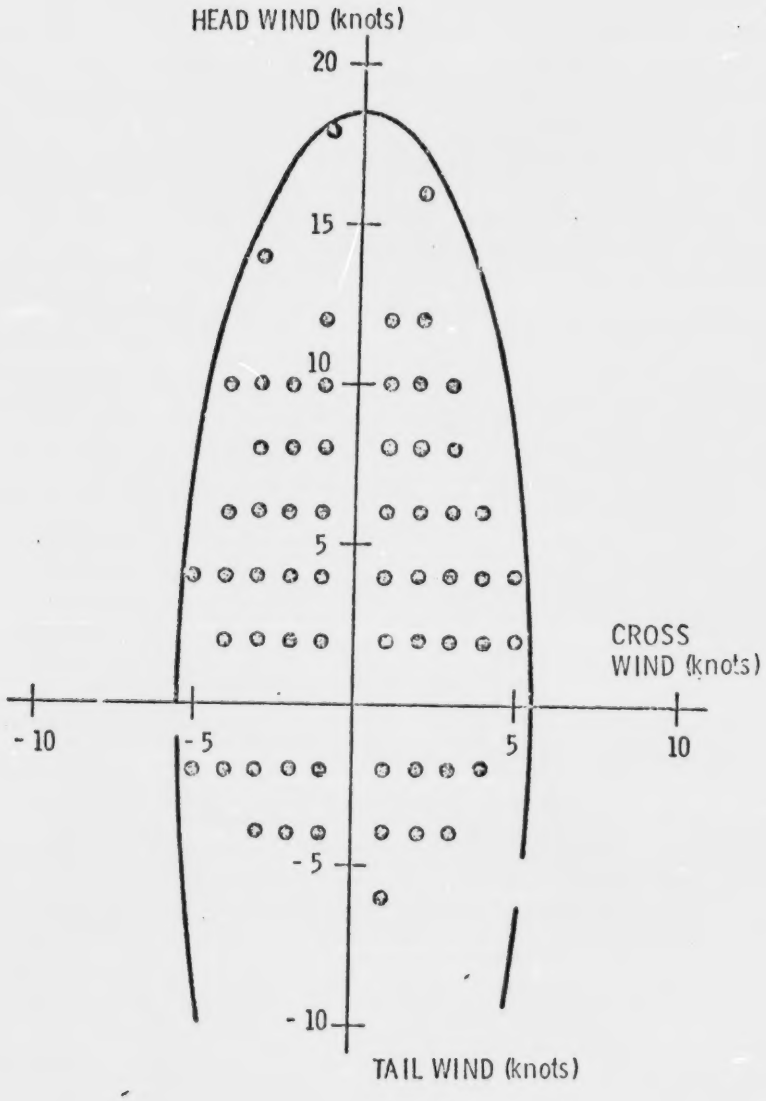


FIGURE 3.2

WIND CONDITIONS WHICH LED TO RESIDENCE TIMES IN EXCESS OF 90 SECONDS AT TIA

SOURCE: Reference 3.

made within these restrictions. When the wind is strong, it may not be possible to change runways for noise abatement. The selection of runways for reason of wind conditions takes precedence over noise abatement restrictions.

The traffic at TIA, as at most airports, has two peak periods, one between eight and nine o'clock in the morning, and one in the late afternoon, with the latter peak dominant (see Figure 3.3). These are the times that delays would occur and build up, and relief from wake turbulence restrictions would be most beneficial. The wind tends to be stronger in the afternoon than in the morning. This is borne out by the statistics. Figure 3.4 shows the mean wind velocity at TIA, over a ten year period, as computed by the Atmospheric Environment Service (AES) of Environment Canada for morning and afternoon hours. Since the difference may be significant for the effectiveness of the wake vortex visualization system, separate wind roses were computed for a critical morning hour - 9:00 a.m. - and afternoon hour - 18:00 p.m. local time. It is also seen that the wind tends to be stronger in the winter than in the summer. This is opposite to the distribution of the traffic, where levels are generally higher in the summer than in the winter (see Section 3.4). In view of these opposite differences, wind statistics were grouped into winter (November through April) and summer (May through October) periods, for the purpose of wind rose computations (Figures 3.5A, B, C and D).

The 15 knots cross-wind component limits have been superimposed on these wind roses for the two main runway orientations. This makes it possible to determine the wind conditions which cause the controllers to select the appropriate runway configurations. These conditions are marked by the heavy lines. Adding the observation frequencies within these borders (taking fractions of the blocks shared by other configurations), the utilization of those configurations during the hours and seasons indicated can be estimated. Although uncertainty exists for the light wind conditions, where controllers have freedom to select one or the other configuration, the estimates for 9:00 a.m. and 18:00 p.m. for 1970 to 1979, as shown in Table 3.1, agree quite well with the actual percentages for the 17 hour per day operations in 1978 and 1979 (Table 2.3). It is seen that the utilization of 'a' is likely to be higher in the morning hours than the all day average, due to the calmer wind conditions, while in the afternoon the present actual utilization of 'a' may be higher than the theoretical one due to the reluctance to use the single Runway 14/32.

FIGURE 3.3

IFR MOVEMENTS
JULY 24, 1980

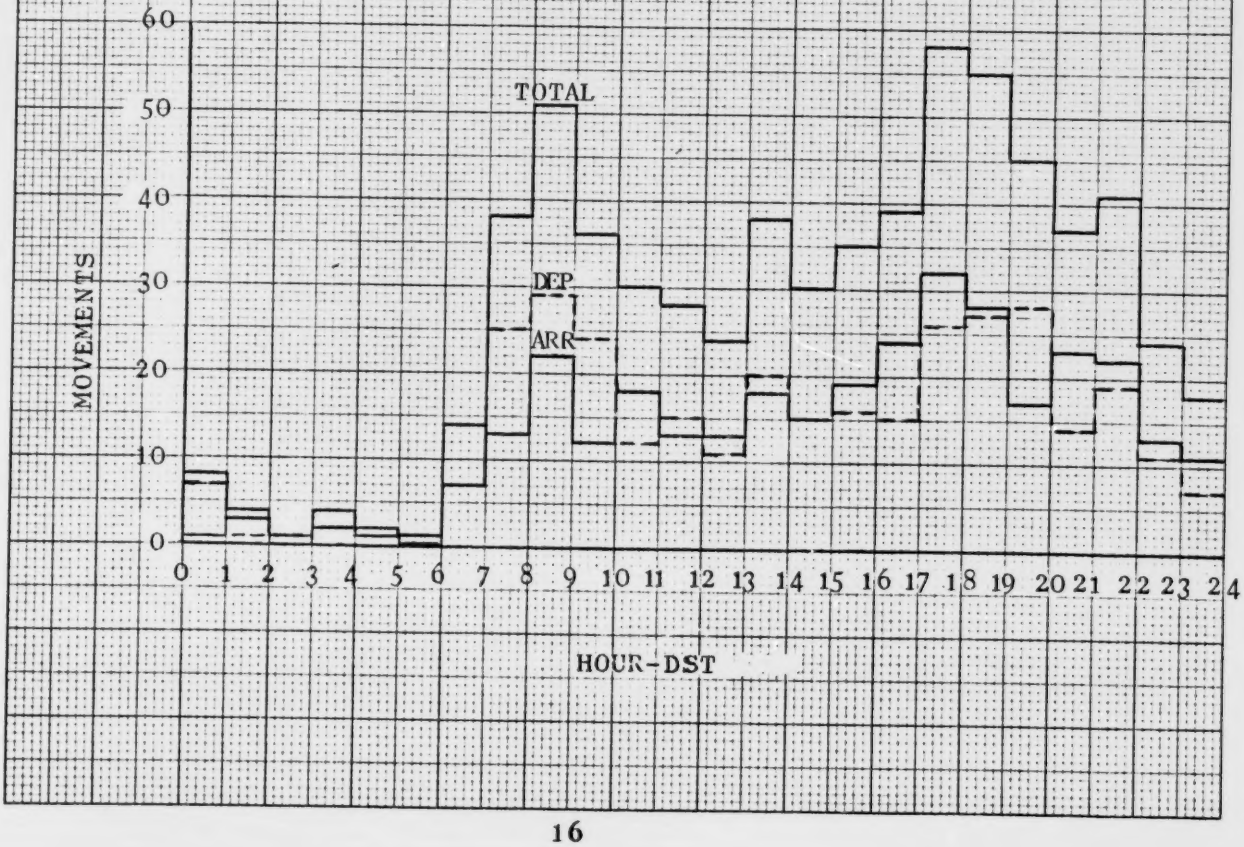


FIGURE 3.4

MEAN WIND SPEED, ALL DIRECTIONS 1970-1979

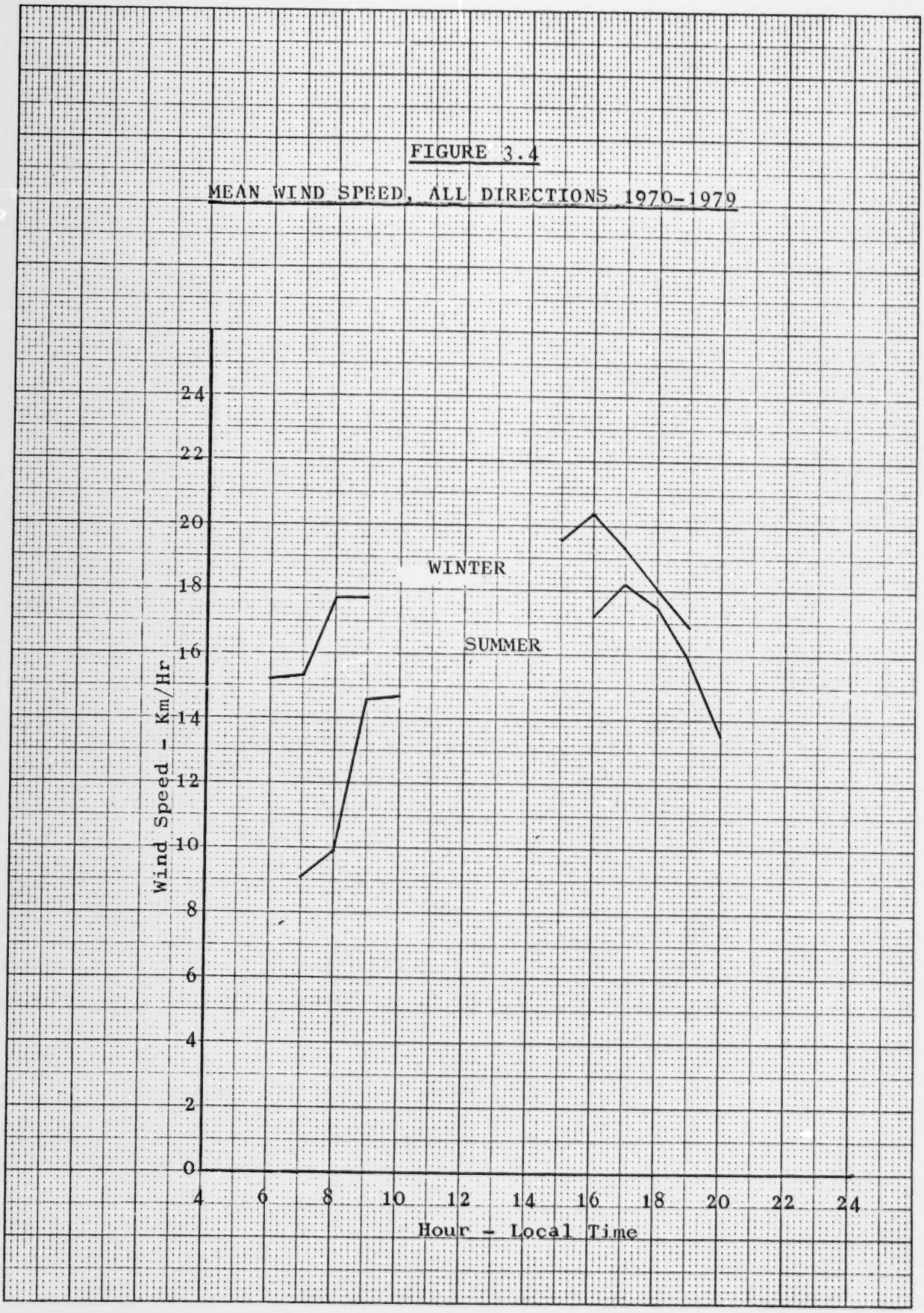
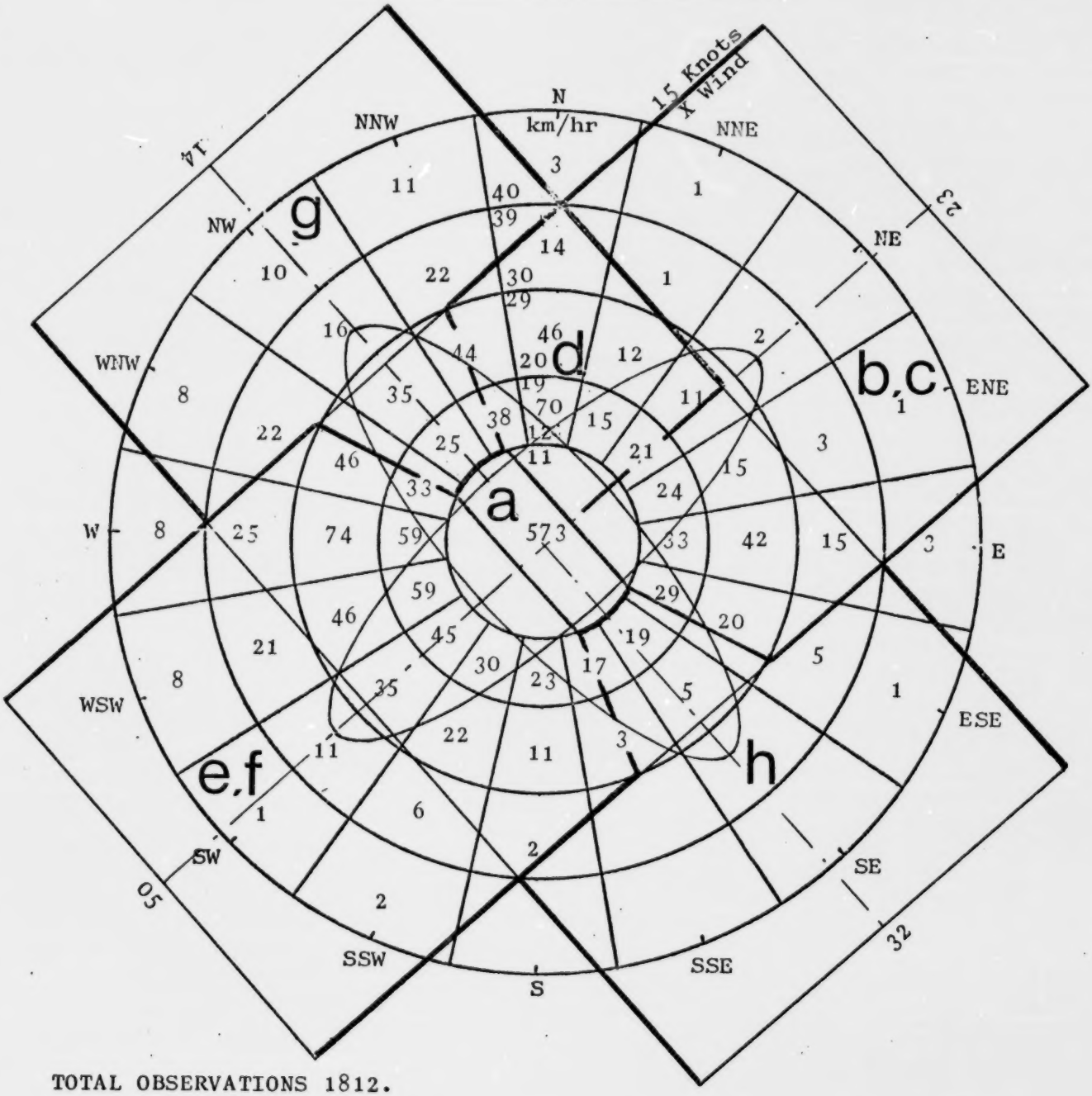


FIGURE 3.5A

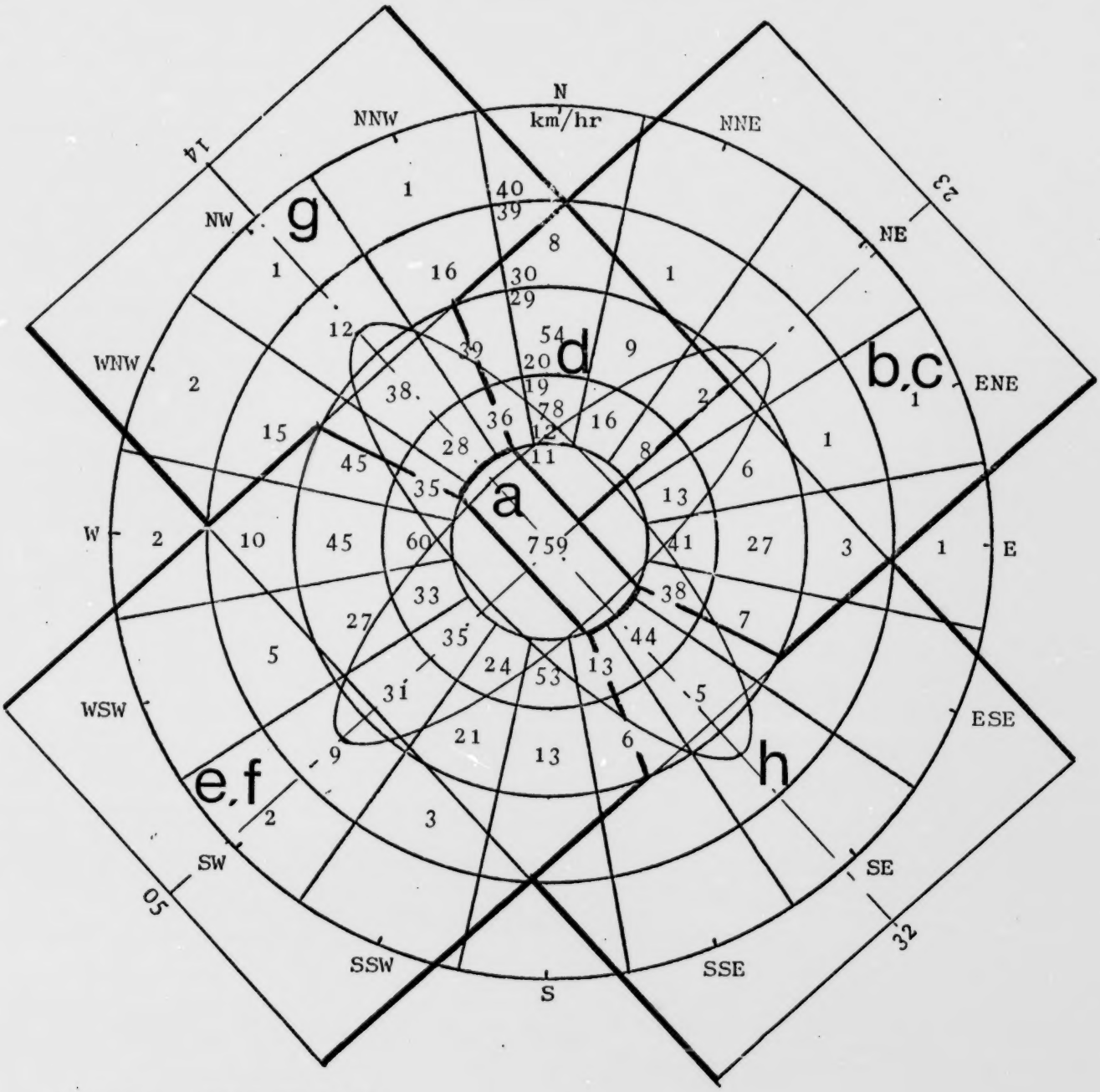
WIND ROSE AT 09:00 EST 1970-1979
WINTER
NOVEMBER THROUGH APRIL



TOTAL OBSERVATIONS 1812.

FIGURE 3.5B

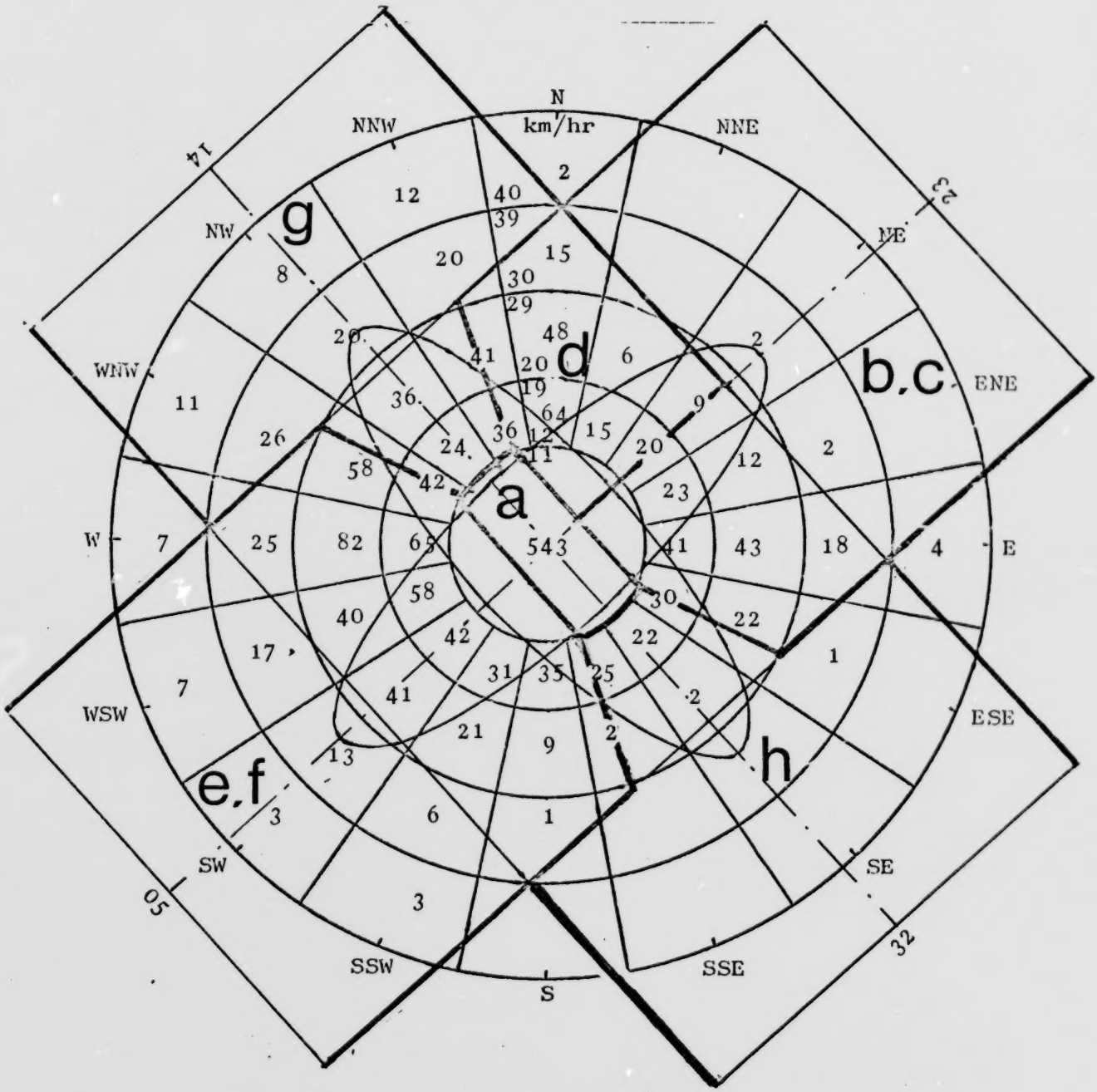
WIND ROSE FOR 09:00 DST 1970-1979
SUMMER
(MAY THROUGH OCTOBER)



TOTAL OBSERVATIONS 1840

FIGURE 3.5C

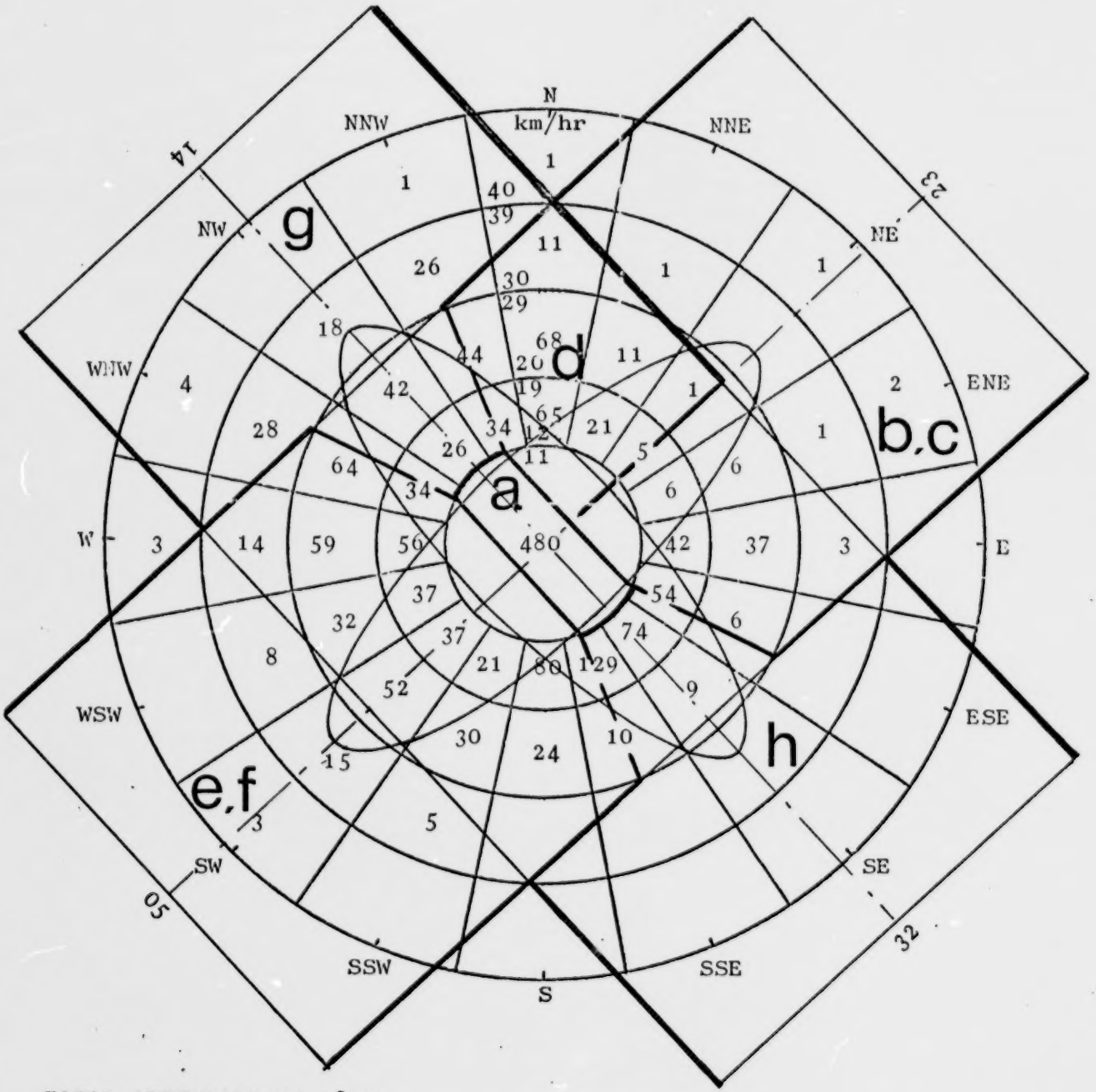
WIND ROSE AT 18:00 EST 1970-1979
WINTER
(NOVEMBER THROUGH APRIL)



TOTAL OBSERVATIONS 1812.

FIGURE 3.5D

WIND ROSE AT 18:00 DST 1970-1979
SUMMER
(MAY THROUGH OCTOBER)



TOTAL OBSERVATIONS 1840.

TABLE 3.1

THEORETICAL UTILIZATION OF RUNWAY CONFIGURATION - PERCENT
1970-1979

CONFIGURATION	09:00 a.m.		18:00 p.m.	
	WINTER	SUMMER	WINTER	SUMMER
a	18	22	12	14
b + c	10	12	13	12
d	15	16	14	16
e + f	38	33	44	35
g	13	9	11	12
h	3	7	3	11
Other	3	1	3	-
Total	100	100	100	100

Also superimposed are the ellipses for the main runway orientations in accordance with Figure 3.2. The potential of a wake vortex visualization system to effect reduction of separations can now be calculated from the frequency that the wind vector is outside the ellipses for each configuration, as a proportion of the time that the configuration is used. The result of these calculations is given in Table 3.2. As it is obvious that for configuration 'a' no benefit could be derived from a wake vortex visualization system, due to the calm wind conditions, the simulation of operations with configuration 'a' was dropped.

3.4 Traffic Forecasts

3.4.1 Planning Peak-Day Movements

As specified in the Terms of Reference Transport Canada forecasts are used for the period beyond 1990. Table 3.3 gives a summary of the aircraft movement forecast for TIA-Malton for 1991 and 1996 as obtained from Statistics and Forecasts (Air).

For the simulation of the commercial carriers, a listing for 1991 of arrivals and departures by aircraft type for each hour of the peak planning day was derived from the schedule forecasts of the Canadian Air Transportation Administration (CATA) (see Appendix Table A.1). However, rather than following the exact CATA schedule, a random number generator was used to determine arrival and departure times.

To obtain a forecast of the General Aviation (GA) IFR movements TIA tower records of two peak-days (July 24 and 30) in 1980 were analyzed to determine percentage IFR movements and hourly distribution: Table A.2 and A.3[1)]. This analysis also shows that 40 per cent of GA IFR traffic belonged to the "medium" weight group (6). The results were scaled up to 1991 levels with the ratio of total GA movements of the forecast. Table 3.4 gives the hourly distribution of IFR arrivals and departures for the peak planning day in 1991 obtained in this manner.

3.4.2 Distribution of Daily Movements

The performance of queueing systems is very sensitive to demand levels near the saturation points. While the system may be saturated on peak-days, there may be little or no delays on days when the demand is 10 to 20 per cent

1) The Monthly Reports of Aviation Statistics do not breakdown IFR and VFR movements into air carriers and General Aviation.

TABLE 3.2

POTENTIAL FOR REDUCTION OF SEPARATION - PERCENT

CONFIGURATION	09:00 a.m.		18:00 p.m.	
	WINTER	SUMMER	WINTER	SUMMER
a	0	0	0	0
b,c	38	44	61	60
d	49	46	51	66
e,f	55	46	45	57
g	46	30	50	46
h	15	2	15	3
Other	-	-	-	-

TABLE 3.3

SUMMARY OF AIRCRAFT MOVEMENT FORECASTS

YEAR	ITINERANT			LOCAL	TOTAL	PEAK PLANNING DAY
	AIR CARRIER	GENERAL AVIATION	TOTAL			
1991	236,000	139,800	375,800	10,000	385,800	1,280
1996	278,400	162,100	440,500	10,000	450,000	1,489

TABLE 3.4

TYPICAL HOURLY IFR DEMAND DISTRIBUTION AND MIX - 1991

HOURS	ARRIVALS				DEPARTURES				GRAND TOTAL
	H	M	L	TOTAL	H	M	L	TOTAL	
0-1	0	1	1	2	0	2	2	4	6
1-2	0	1	3	4	0	0	1	1	5
2-3	0	1	0	1	0	0	1	1	2
3-4	0	1	2	3	0	1	0	1	4
4-5	0	1	0	1	0	0	1	1	2
5-6	0	0	1	1	0	1	0	1	2
6-7	0	0	1	1	1	1	1	3	4
7-8	11	8	1	20	4	21	5	30	50
8-9	8	14	3	25	12	22	6	40	65
9-10	7	17	5	29	16	14	2	32	61
10-11	4	13	5	22	6	15	3	24	46
11-12	4	10	2	16	6	12	2	20	36
12-13	7	15	1	23	3	12	3	18	41
13-14	5	10	2	17	3	12	4	19	36
14-15	8	12	2	22	5	13	2	20	42
15-16	11	15	2	28	4	16	5	25	53
16-17	14	14	3	31	4	16	4	24	55
17-18	16	13	4	33	13	16	5	34	67
18-19	9	20	6	35	15	15	3	33	68
19-20	12	14	2	28	18	12	1	31	59
20-21	10	14	4	28	9	11	1	21	49
21-22	8	19	4	31	9	6	1	16	47
22-23	7	10	1	18	9	8	2	19	37
23-24	1	3	2	6	4	1	2	7	13
Total	142	226	57	425	141	227	57	425	850

below the saturation point. It is important, therefore, to determine the distribution of demand levels over the year, if total delay costs over the year are to be computed.

Traffic levels are seasonal, but this seasonal variation is not apparent from the forecasts. The monthly distribution of IFR traffic volumes was, therefore, obtained from the March 1979 to February 1980 Monthly Reports (Table 2.2), see Figure 3.6, and this percentage distribution was applied to the 1991 forecast of itinerant movements. However, it was reasoned that the proportion of IFR traffic would tend to be greater in 1991 as General Aviation operates more jet aircraft, aircraft will be better instrumented and more pilots will get IFR rating. This may be offset to some degree by pilots opting for VFR approaches in order to get faster clearance. The total of IFR movements in 1991, which would be 310,864 by 1979/1980 standards, was, for these reasons, assumed to be 315,000.

It is also well known that weekends tend to be less busy than working days. The two influences, seasonal and day-of-the-week act together to make for substantial variations in traffic demand through the year. The traffic distribution over the week was derived from the records of IFR movements for each day of the March 1979-February 1980 period (Appendix Table A.4), and is shown in Figure 3.7. It turned out that Wednesdays and Fridays have approximately the same levels (15.5 per cent), Thursday is the peak-day (16 per cent), Saturdays and Sundays also having the same levels (12 per cent) whilst Monday is in between with 14 per cent.

The distribution by month and by day-of-the-week yielded the daily IFR traffic levels for 1991 and 1996.[1] These levels were grouped in blocks of 50 for use in the delay calculations (Table 3.5A and B).

3.5 Units of Cost

Delays of traffic due to congestion can be given monetary values due to the operating cost of the aircraft and the value of the passengers' time wasted.

3.5.1 Aircraft Operating Cost

Since this study is concerned with reduction in delays and hence cost saving, only direct operating cost of aircraft are applicable. These costs include fuel, crew, maintenance and insurance. Average operating costs differ

[1] Total volume for February 1991 was scaled down from the 1980 figures as 1980 was a leap year and 1991 will not be.

FIGURE 3.6

ANNUAL DISTRIBUTION OF IFR TRAFFIC

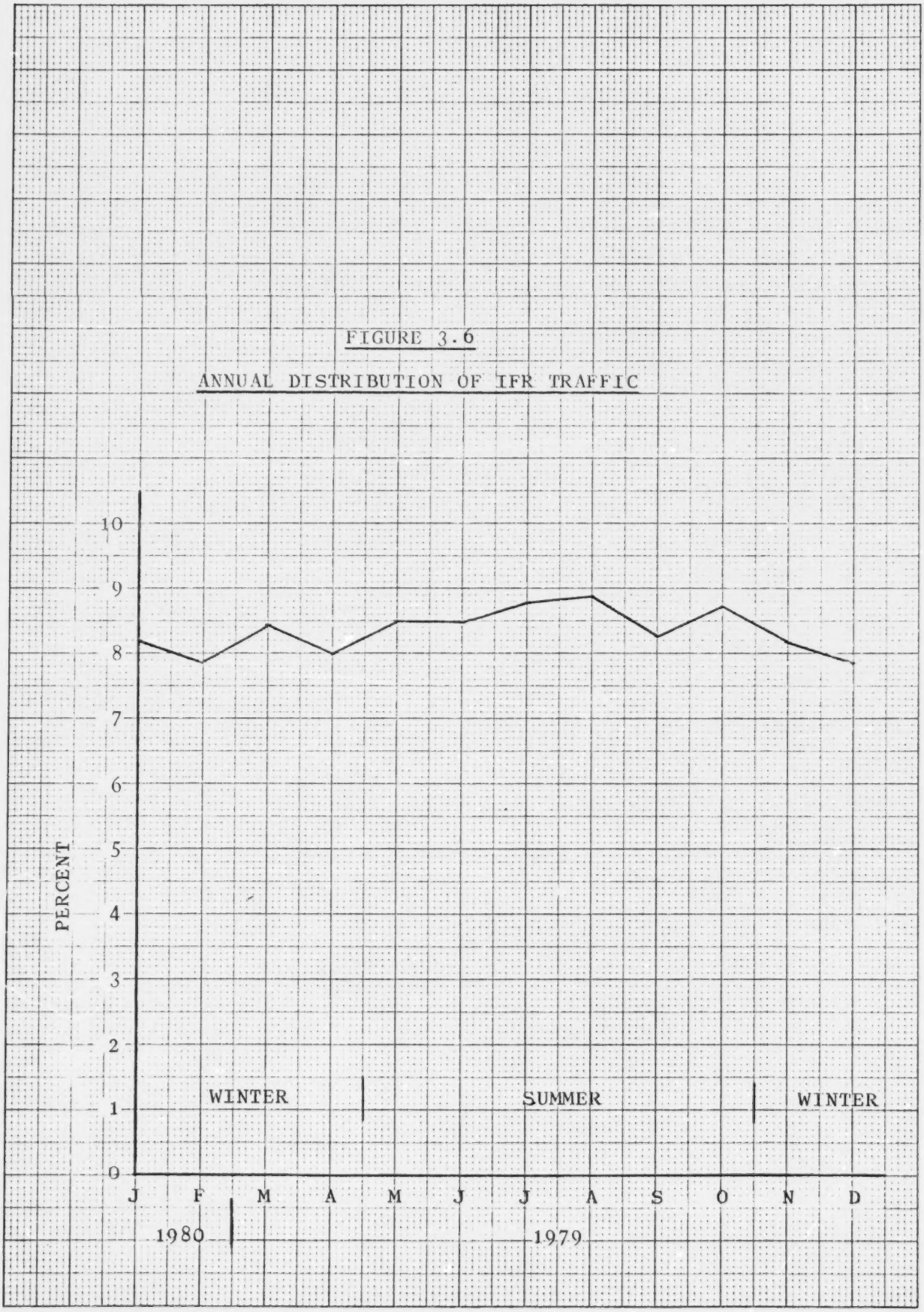


FIGURE 3.7

IFR TRAFFIC DISTRIBUTION THROUGH THE WEEK

TABLE 3.5A

1991 DAILY IFR MOVEMENTS

		MON	TUE	WED/FRI	THU	SAT/SUN
W	January	815	873	903	932	699
I	February	837	897	927	957	718
N	March	840	900	930	960	720
T	April	821	880	909	939	704
S	May	846	907	937	967	725
U	June	873	936	967	999	749
M	July	872	934	965	997	747
M	August	883	946	978	1009	757
E	September	846	906	937	967	725
R	October	867	929	960	991	743
E	November	838	898	928	957	718
R	December	779	835	863	891	668

Summary	Movements	Days Winter	Days Summer
	1001-1050	0	4
	951-1000	12	57
	901-950	55	41
	851-900	34	18
	801-850	26	9
	≤800	54	55
		181	184

TABLE 3.5B

1996 DAILY IFR MOVEMENTS

		MON	TUE	WED/FRI	THU	SAT/SUN
W	January	961	1030	1066	1100	789
I	February	988	1058	1094	1129	847
N	March	991	1062	1097	1133	850
T	April	969	1038	1073	1108	831
S	May	998	1070	1106	1141	855
U	June	1030	1104	1141	1179	884
M	July	1029	1102	1139	1176	881
M	August	1042	1116	1154	1191	893
E	September	998	1069	1106	1141	855
R	October	1023	1096	1134	1169	877
E	November	989	1059	1095	1129	847
R	December	919	985	1018	1051	788

Summary	Movements	Days Winter	Days Summer
	1151-1200	0	26
	1101-1150	17	66
	1051-1100	65	13
	1001-1050	18	18
	951-1000	26	9
	901-950	4	0
	851-900	0	52
	801-850	35	0
	$\leq$ 800	17	0
		182	184

with airlines due to fleet size, route structure, bookkeeping methods etc. For each aircraft type the average of the cost data given by three operators was used whe e possible (4). For the B-767 and B-757 which are not flying yet, costs were obtained from Boeing sales literature. The cost for normal operation was reduced to account for lower fuel consumption in holding for arrival delays and idling for departure delays. Also maintenance cost is reduced for ground operations. Analysis showed that the cost of ground delays was about 60 per cent of that of airborne delays.

In the future airborne delays will be minimized by flow control and cost of departure delays will be minimized by advance warning before starting engines, but such refinements go beyond the scope of this study. Table 3.6 lists the hourly cost for aircraft in the CATA forecast and some typical General Aviation IFR aircraft.

3.5.2 Value of Passenger Time

3.5.2.1 Passenger Break Down by Purpose of Trip

The airline passengers can be divided into two categories for cost assessment purposes: business and tourist. Air Canada has held surveys in an effort to establish the proportions of these categories but the results were not satisfactory.

A rough estimate made by Air Canada is a 50/50 ratio for domestic traffic (as an average between 90/10 on short flights into Toronto and 10/90 on long haul routes for business/tourist ratio).

For international flights a 30/70 ratio of business to tourist travellers was estimated on the basis of information obtained from the International Civil Aviation Organization (ICAO). International (including trans-border) flights form 49.5 per cent of Toronto's traffic, so that in total a 40/60 ratio of business to tourist travel results. The occupants of medium weight General Aviation aircraft are assumed to be all business travellers.

3.5.2.2 Value of Business Time

It may be assumed that the large majority of business travellers is "managerial" and therefore not entitled to overtime payment. The average annual payroll cost of this group can be estimated at $40,000. (including benefits). Based on a 35 hour work-week this amounts to $25 per hour.

When arrival delays cause the missing of connections and no later connections are available, extra meals, overnight accommodation and transportation are involved. This may occur in the case of transfer passengers on late afternoon flights. Connecting passengers on arriving

flights at TIA account for approximately 20 per cent of total traffic, so that it can be estimated that some 5 per cent of passengers, arriving on critical flights, are exposed to that risk, which would occur if delays exceed, say, one hour. For delays less than an hour, the value of business travellers time may be taken equal to payroll cost. These costs can be added to the hourly operating cost of the aircraft.

It is sometimes argued that for small delays no costs should be claimed. However, when delays occur more than rarely, the business traveller will need to take an earlier flight or otherwise charge for the greater time spent in travelling.

3.5.2.3 Value of Leisure Time

Delays of tourists or Visiting Relatives and Friends (VRF) travellers, do not entail any loss of salary, additional hotel or transportation costs, unless the passenger is involved in missed connections.

The probability and the cost of such occurrence can be assumed to be the same as in the case of business travellers.

Many tourists travel on reduced fares (excursion or charter) and make allowances for inconveniences unless they become excessive. Therefore for delays for less than one hour no monetary cost can be charged, or in reverse, for a saving of less than one hour no monetary credit can be claimed.

3.5.3 Load Factor

In the CATA traffic forecast for air carriers, load factors were included to estimate passenger flows. The load factors vary by route, time of day, scheduled or charter flight etc. It would not be possible to assign different load factors to each flight in the simulation since varying demand levels, representing different years and seasons are run. Therefore an average load factor of 70 per cent was assumed. The resulting passenger loads for each aircraft type as well as the total of aircraft cost and passenger time value are also shown in Table 3.6.

General Aviation IFR flights are practically all business flights and air taxi flights. From an FAA survey (5) the average size and seat occupancy is known. The load factor is 52 to 58 per cent. In the absence of a Canadian study, these figures are adopted for TIA and included in Table 3.6.

TABLE 3.6

1980 DIRECT DELAY COSTS - CDN $/HOUR[1)]

	TYPE	AIRCRAFT $/HR		PASSENGERS		TOTAL $/HR	
		ARR	DEP	LOAD	$/HR	ARR	DEP
H	B-747	5,220	3,130	300	3,000	8,220	6,130
	DC-10[2)]	3,400	2,040	210	2,100	5,500	4,140
	B-767	2,750	1,650	150	1,500	4,250	3,150
M	B-757	2,400	1,440	130	1,300	3,700	2,740
	B-727	1,920	1,150	100	1,000	2,920	2,150
	B-737	1,180	710	70	700	1,880	1,410
	DC-9	1,390	830	75	750	2,140	1,580
	DHC-7	490	290	35	350	840	640
	HS-125[3)]	360	220	5.4	135	495	355
L	C-441	280	170	5.7	145	425	315
	C-402	140	85	3.8	95	235	180

1) Converted from (4) by $1 CDN = $0.85 U.S.

2) Average of L-1011, DC-10.

3) Average of CL-600, CE-65, HS-125, LR-55, NA-65, IAL 112.

3.5.4 Weighted Average Cost Per Minute

With the proportion of aircraft of each type in the mix as derived from Tables A.1 and A.2, weighted average cost per minute can be computed for each weight class. The result is given in Table 3.7.

3.6 Calculation of Total Benefits

With the various factors determined, the benefit can be calculated from the reduction in delays which can be expected without the wake turbulence separation compared to those with full wake turbulence separation, under the respective conditions.

Thus the net benefits are obtained as the sum of the savings in dollars, from dollars cost per minute times expected value of delay reduction in minutes, for the percentage of time that relief from wake turbulence restriction can be allowed in each runway configuration, during the percentage of time that such runway configuration can be expected to be utilized. These savings must be calculated for each flight mode (arrival or departure) for each weight class, for the number of days that each volume of movements is considered for each season for each year.

In mathematical terms this can be expressed as

$$T = \sum_{y=1}^{10} \sum_{s=1}^{2} \sum_{f=1}^{2} \sum_{w=1}^{3} W_w \sum_{m} M_{f,m} \times D_{y,s,m} \times \sum_{c=1}^{8} U_c \times R_c \times E(d)_{f,m,c,w} \times S_{f,w}$$

Where,

T = total savings over ten years.

y = year (1991 = 1)

s = season (winter = 1)

f = flight mode (arrival = 1)

m = movement volume bracket (801-850 = 1)[1)]

M = movement volume, average in bracket m

D = number of days of given movement volume

w = weight class (heavy = 1)

[1)] For movements less than 800 per day, negligible savings are realized, see Figure 4.2, Page 43.

W = percentage of aircraft in given weight class

c = runway configuration (a = 1)

U = utilization of runway configuration c in percent

R = probability that wake turbulence restrictions can be lifted, given operation in runway configuration c

E(d) = expected value of delay reduction in minutes

S = savings in dollars per minute of aircraft operation and passenger time.

The values for the variables in the equation can be found from the following tables and figures:

$D_{y,s,m}$: Tables 3.5A and B

U_c : Table 3.1

R_c : Table 3.2

$E(d)_{f,m,c,w}$: Figure 4.2

$S_{f,w}$: Table 3.7.

TABLE 3.7

TOTAL COST OF DELAYS - $/MIN

	ARRIVAL	DEPARTURE
Heavy:	88.50	66.00
Medium:	35.50	26.50
Light:	5.50	4.10

4. CALCULATION OF DELAY TIMES

4.1 Input

The aircraft parameters and resulting runway occupancy times, used in the simulation are shown in Table 4.1. The approach and departure distances resulting from glide path slope and interception altitude are shown in Table 4.2. Separation times following from prescribed separation distances, with and without wake turbulence restrictions are given in Table 4.3.

The simulation was run for the three runway configurations at four demand levels, corresponding to daily movement levels of 771, 895, 1020 and 1141[1] operations. These levels span the range of low 1991 to high 1996 IFR traffic levels, as shown in the Forecast section. The proportion of heavy, medium and light aircraft was taken the same at each level.

4.2 Output

The computer output tabulates the delays that occur in sequencing aircraft landing and taking-off. The results are provided in two forms for each runway configuration, both with and without wake turbulence separation standards. The output is reproduced in the Appendix:

Tables A.5 Summary of average delay to arrivals and departures in each hour of the day.

Tables A.6 Number of arrivals and departures assigned to each runway along with the mean delay by aircraft for each wake turbulence classification.

The average total delay to arrivals and departures from Tables A.5 is plotted in Figure 4.1 to show the difference due to application of wake turbulence separation and the effect of volume of movements.

The reduction in delays which would result by cancellation of wake turbulence separation is apparent from Figure 4.2 for each aircraft weight class. For a traffic level of 1,020 movements/day the average delay by hour, separate for arrivals and departures, is plotted for each runway configuration in Figure 4.3 to 4.5, with and without wake turbulence restrictions.

[1] These levels were called 60, 70, 80 and 90 per cent demand respectively.

TABLE 4.1

AIRCRAFT PARAMETERS AND RUNWAY OCCUPANCY TIMES

AIRCRAFT	APPROACH SPEED (KTS)	LANDING RUNWAY OCCUPANCY TIME (SEC)	TAKE-OFF ACCELERATION (FT/SEC^2)	TAKE-OFF RUNWAY OCCUPANCY TIME (SEC)	CLIMB SPEED (KTS)
H	160	57	6	46	165
M	140	51	6	42	150
L	110	42	6	24	85

TABLE 4.2

RUNWAY PARAMETERS

RUNWAY NAME	APPROACH DISTANCE (NM)	COMMON DEPARTURE DISTANCE (NM)
24	10.3	6.
32	9.3	6.
5L	10.3	6.
23R	9.3	6.
5R	9.3	6.
23L	9.3	6.

TABLE 4.3

SEPARATION TIMES

SEPARATION AT START OF APPROACH (MINS)

		Following Aircraft		
		H	M	L
Leading Aircraft	H	2.32	2.14	3.27
	M	1.5	1.29	2.18
	L	2.32	2.10	1.64

With Wake Turbulence Restrictions

		Following Aircraft		
		H	M	L
Leading Aircraft	H	1.125	1.29	1.64
	M	1.5	1.20	1.64
	L	2.32	2.10	1.64

Without Wake Turbulence Restrictions

DEPARTURE SEPARATION (MINS)

		Following Aircraft		
		H	M	L
Leading Aircraft	H	1.45	1.82	2.00
	M	1.42	1.20	1.60
	L	2.00	2.00	2.00

With Wake Turbulence Restrictions

		Following Aircraft		
		H	M	L
Leading	H	1.09	1.09	1.09
	M	1.42	1.20	1.20
	L	2.00	2.00	2.00

Without Wake Turbulence Restrictions

FIGURE 4.1

AVERAGE DELAY WITH AND WITHOUT WAKE TURBULENCE RESTRICTIONS

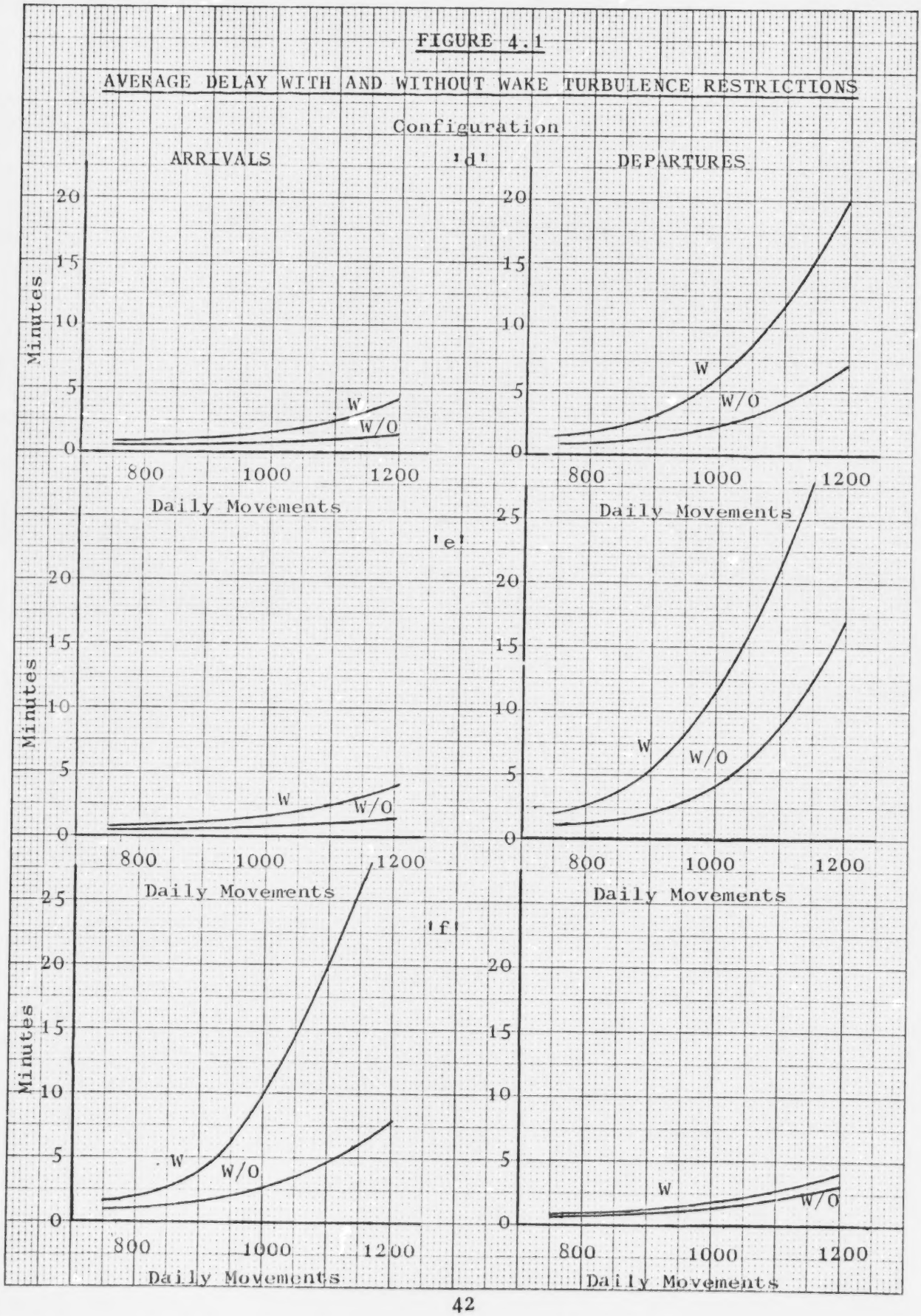


FIGURE 4.2

REDUCTIONS IN DELAY BY LIFTING WAKE TURBULENCE RESTRICTIONS

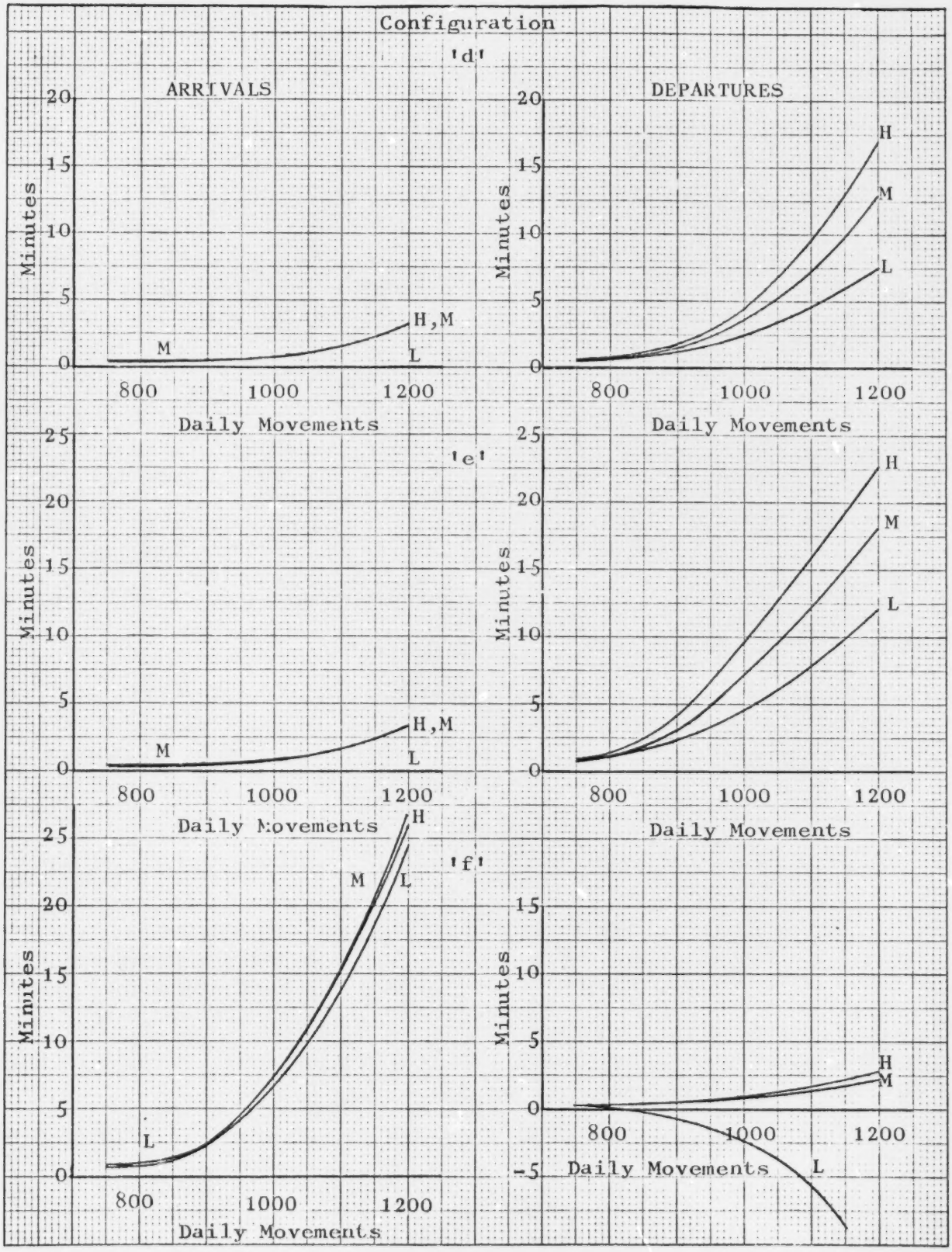


FIGURE 4.3

Average Delay for Configuration "d" for 1020 Operations/Day - IFR

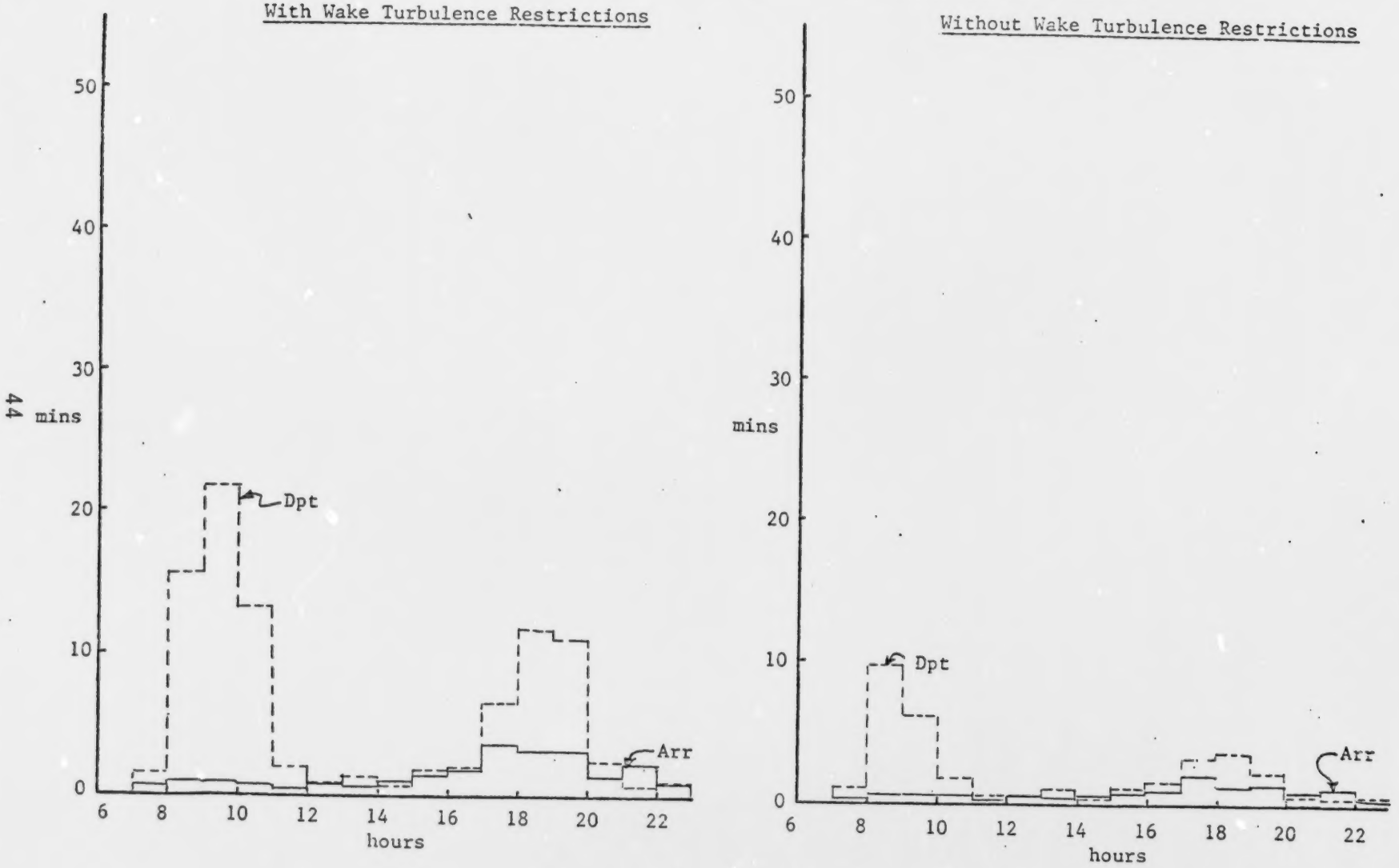


FIGURE 4.4

Average Delay for Configuration "e" for 1020 Operations/Day - IFR

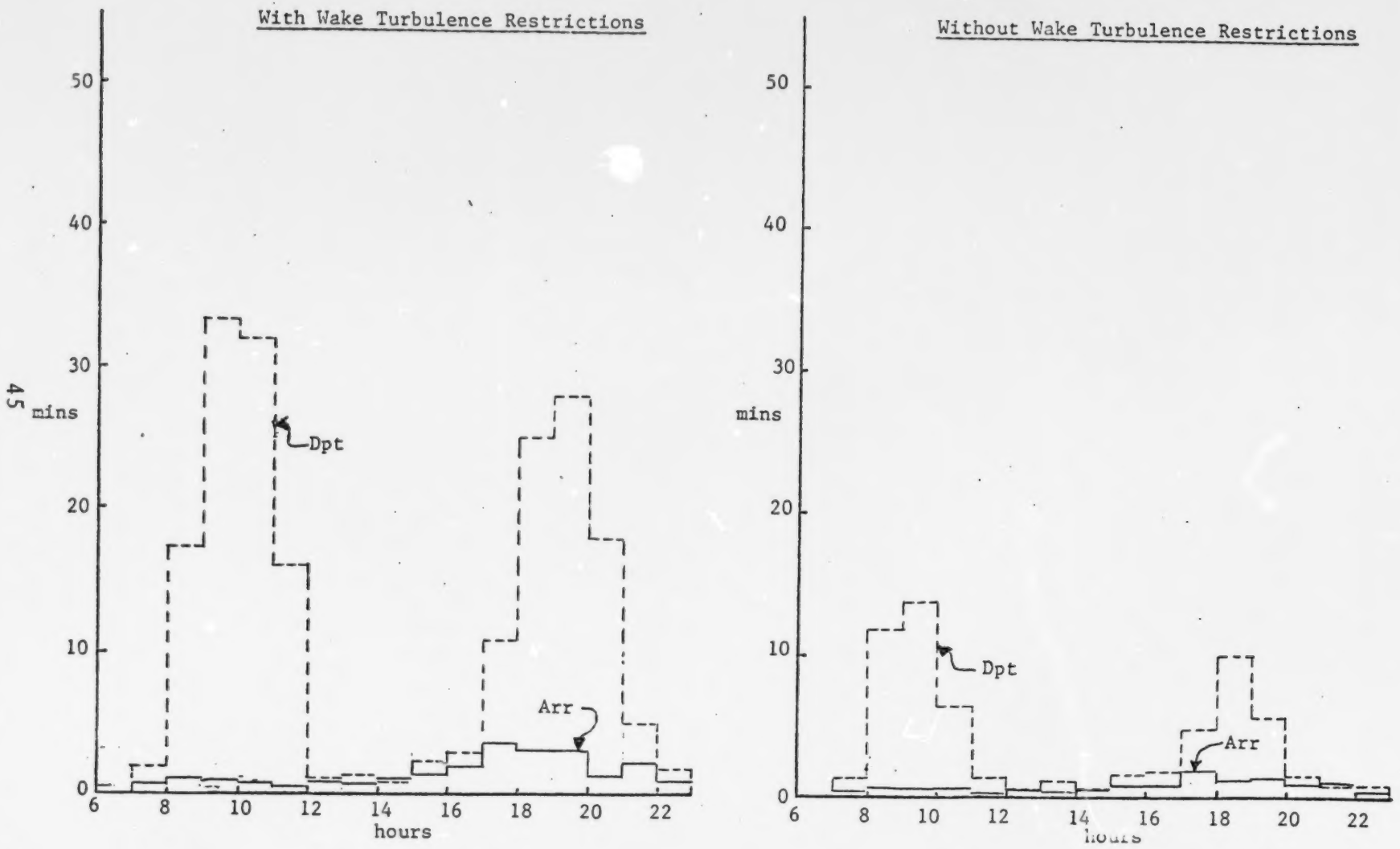
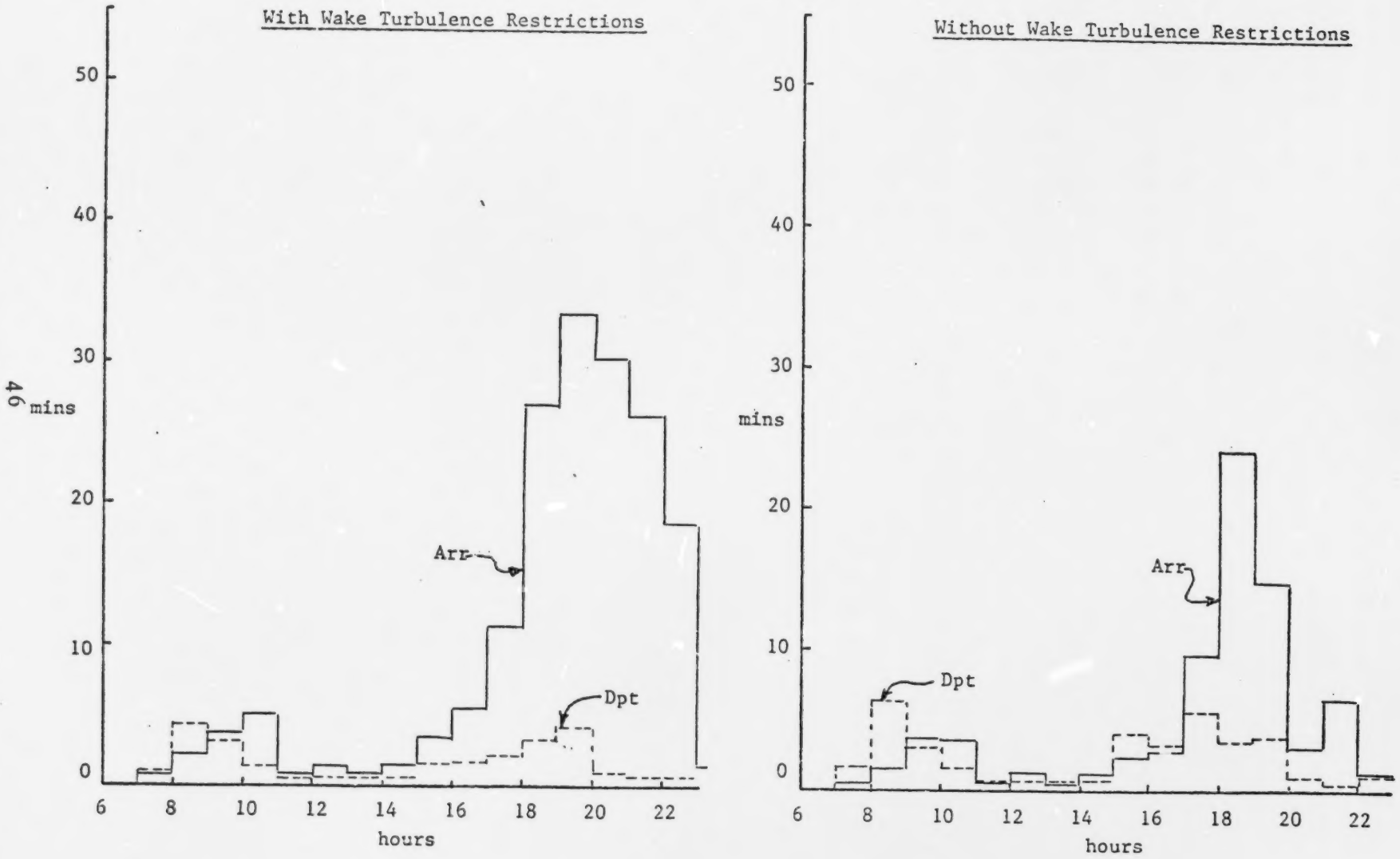


FIGURE 4.5

Average Delay for Configuration "f" for 1020 Operations/Day IFR



5. CALCULATION OF COST SAVINGS

Results of the calculations, performed according to the method outlined in Section 3.6 are given in summary in Tables 5.1 to 5.4. For the arrival delays the utilization of the runway configuration and the percentage of time that the wind vector is outside the ellipse in the afternoon (18:00 p.m.) is used. For departure delays the average of the respective figures for morning (9:00 a.m.) and afternoon is used.

Results of the calculations show a theoretical potential benefit of $8.3 million in 1991, increasing to $33.3 million by 1996. The actual savings will, on the one hand be less due to problems in transition from one set of standards to another, and on the other hand may be higher if the general practice of operating into wind would be changed to operating with cross-wind. The dollar amounts are very sensitive to price of fuel and to value of passenger time. Savings for light aircraft are insignificant compared to those for medium and heavy aircraft and their passengers.

Savings in investment of runway construction do not appear to be possible because greater separations are necessary for a substantial percentage of the time; this is due to the prevalence of light winds which are conducive to long wake vortex life.

TABLE 5.1

POTENTIAL SAVINGS - WINTER 1991
($ 000)

FLIGHT PHASE: ARRIVALS

WEIGHT CLASS		HEAVY			MEDIUM			LIGHT		
Movements	Days	CONFIGURATION			CONFIGURATION			CONFIGURATION		
		d	e,c,g,h	f,b	d	e,c,g,h	f,b	d	e,c,g,h	f,b
801-850	26	9	22	29	7	19	19	0	0	1
851-900	34	16	41	72	10	26	47	0	0	2
901-950	55	32	88	262	21	57	169	0	0	6
951-1000	12	9	24	103	6	16	66	0	0	2
Total		66	175	466	44	118	301	0	0	11
All configurations			707			463			11	
All aircraft			1,181							

FLIGHT PHASE: DEPARTURES

WEIGHT CLASS		HEAVY			MEDIUM			LIGHT		
Movements	Days	CONFIGURATION			CONFIGURATION			CONFIGURATION		
		d	e,c,g,h	f,b	d	e,c,g,h	f,b	d	e,c,g,h	f,b
801-850	26	17	99	9	9	53	5	0	1	0
851-900	34	36	237	15	18	123	10	1	4	0
901-950	55	89	693	30	52	337	20	1	9	-1
951-1,000	12	34	246	8	18	116	4	0	3	-1
Total		176	1,275	62	97	629	39	2	17	-2
All configurations			1,513			765			17	
All aircraft			2,295							
All season			3,476							

TABLE 5.2

POTENTIAL SAVINGS - SUMMER 1991
($ 000)

FLIGHT PHASE: ARRIVALS

WEIGHT CLASS		HEAVY			MEDIUM			LIGHT		
Movements	Days	CONFIGURATION			CONFIGURATION			CONFIGURATION		
		d	e,c,g,h	f,b	d	e,c,g,h	f,b	d	e,c,g,h	f,b
801-850	9	5	8	8	4	7	5	0	0	0
851-900	18	12	24	28	8	15	18	0	0	1
901-950	41	35	71	146	24	47	97	0	0	3
951-1,000	57	61	125	364	39	81	235	0	0	8
1,001-1,050	4	5	12	42	3	8	27	0	0	1
Total		118	240	588	78	158	382	0	0	13
All configurations			946			618			13	
All aircraft			1,577							

FLIGHT PHASE: DEPARTURES

WEIGHT CLASS		HEAVY			MEDIUM			LIGHT		
Movements	Days	CONFIGURATION			CONFIGURATION			CONFIGURATION		
		d	e,c,g,h	f,b	d	e,c,g,h	f,b	d	e,c,g,h	f,b
801-850	9	7	33	2	4	18	1	0	1	0
851-900	18	23	119	6	12	62	4	0	2	0
901-950	41	82	490	17	50	246	12	1	6	-1
951-1,000	57	197	1,110	30	106	524	16	3	13	-2
1,001-1,050	4	22	112	3	12	54	2	0	1	0
Total		331	1,764	58	184	904	35	4	23	-3
All configurations			2,153			1,123			24	
All aircraft			3,300							
All season			4,877							

TABLE 5.3

POTENTIAL SAVINGS - WINTER 1996
($ 000)

FLIGHT PHASE: ARRIVALS

WEIGHT CLASS		HEAVY			MEDIUM			LIGHT		
Movements	Days	CONFIGURATION			CONFIGURATION			CONFIGURATION		
		d	e,c,g,h	f,b	d	e,c,g,h	f,b	d	e,c,g,h	f,b
801-850	35	12	29	39	8	19	25	0	0	1
901-950	4	2	6	19	2	4	12	0	0	0
951-1,000	26	18	52	223	12	34	143	0	0	5
1,001-1,050	18	17	57	252	11	37	162	0	0	6
1,051-1,100	65	95	338	1,398	62	217	900	0	0	31
1,101-1,150	17	38	132	522	25	85	336	0	0	11
Total		184	614	2,453	120	356	1,578	0	0	54
All Configurations			3,251			2,094			54	
All Aircraft			5,399							

FLIGHT PHASE: DEPARTURES

WEIGHT CLASS		HEAVY			MEDIUM			LIGHT		
Movements	Days	CONFIGURATION			CONFIGURATION			CONFIGURATION		
		d	e,c,g,h	f,b	d	e,c,g,h	f,b	d	e,c,g,h	f,b
801-850	35	23	134	11	12	72	7	0	2	0
901-950	4	6	50	2	4	25	1	0	1	0
951-1,000	26	73	534	18	39	252	10	1	6	- 1
1,001-1,050	18	81	531	20	43	257	11	1	6	- 1
1,051-1,100	65	457	2,587	97	219	1,274	54	5	31	- 8
1,101-1,150	17	172	865	38	84	434	20	2	11	- 3
Total		812	4,701	186	401	2,314	103	9	57	-13
All Configurations			5,699			2,818			53	
All Aircraft			8,570							
All Season			13,969							

TABLE 5.4

POTENTIAL SAVINGS - SUMMER 1996
($ 000)

FLIGHT PHASE: ARRIVALS

WEIGHT CLASS		HEAVY			MEDIUM			LIGHT		
Movements	Days	CONFIGURATION			CONFIGURATION			CONFIGURATION		
		d	e,c,g,h	f,b	d	e,c,g,h	f,b	d	e,c,g,h	f,b
851-900	52	35	68	82	23	44	53	0	0	2
951-1,000	9	9	19	57	6	12	37	0	0	1
1,001-1,050	18	25	62	187	16	40	120	0	0	4
1,051-1,100	13	28	73	208	18	47	134	0	0	4
1,101-1,150	66	219	554	1,506	141	357	960	0	0	33
1,151-1,200	26	128	330	812	83	213	510	0	0	18
Total		444	1,106	2,852	287	713	1,814	0	0	62
All Configurations			4,402			2,814			62	
All Aircraft			7,278							

FLIGHT PHASE: DEPARTURES

WEIGHT CLASS		HEAVY			MEDIUM			LIGHT		
Movements	Days	CONFIGURATION			CONFIGURATION			CONFIGURATION		
		d	e,c,g,h	f,b	d	e,c,g,h	f,b	d	e,c,g,h	f,b
851-900	52	67	343	17	35	179	11	1	5	0
951-1,000	9	31	175	4	17	83	2	0	2	0
1,001-1,050	18	100	503	15	53	243	8	1	6	- 1
1,051-1,100	13	113	378	15	54	241	8	1	6	- 1
1,101-1,150	66	826	3,183	114	401	1,598	58	9	39	-10
1,151-1,200	26	448	1,563	58	219	796	30	5	20	- 6
Total		1,585	6,145	223	779	3,140	117	17	78	-18
All Configurations			7,953			4,036			77	
All Aircraft			12,066							
All Season			19,344							

6. DISCUSSION OF RESULTS

It is clear from these figures that arrival delays are incurred almost exclusively in the afternoon with or without wake turbulence restrictions. Departures are delayed during the morning peak-hours in all cases but especially when runway configuration "e" is in use, due to the assignment of Runway 23R to all General Aviation flights in addition to the air carrier departures. When air carrier departures are switched to 23L and arrivals assigned to 23R, as in "f", delays to arrivals are substantial with wake turbulence restrictions, as could be expected, but overall the situation is improved.

The configuration that works best with or without wake turbulence restrictions, is "d", where air carrier arrivals and departures are independent of each other (in contrast to "a") while GA uses a third runway. Departures on 32 can operate independently of arrivals on 05R. However, utilization of "d" is more limited than that of "e" or "f", due to cross-wind restrictions on perpendicular runways.

Delays to light aircraft are the least. For departing light aircraft the application of higher separation standards is more favourable in configuration "f". In this configuration all light aircraft departures are dispatched between arrivals of all classes of aircraft. With the wake turbulence separations, the greater spacing between arrivals allows more departures of light aircraft, and therefore less delay.

The potential savings calculated in this report may be regarded as the maximum obtainable at TIA for the forecast traffic, and with the airport being operated as it is at this time with regard to runway selection relative to wind condition. It was also assumed that in the 1990s Runway 14/32 would have a parallel at least 5,000 feet distant, and that this system would be operated similarly to the 05/23 system now but with the same frequency as 14/32 now. If such would not be the case the configurations "g" and "h" should be deleted from the calculations. However, if no runway parallel to 14/32 exists in the 1990s the delays incurred when wind conditions and noise abatement would make use of the single Runway 14/32 necessary, would probably cause chaos. This would eventually lead to either reduced traffic or construction of a new runway.

As mentioned elsewhere, the percentage of time that the 3 nautical mile separation can be applied has been computed without allowance for transition time from the wake turbulence separation procedures.

On days when a steady wind blows in a sector of the wind rose outside the ellipse for wake vortex longevity, no transition problems occur. Similarly on calm wind days, the full wake vortex separation would remain in force. On days where the wind is weak in the morning, but increases during midday, the transition could probably be made during the relatively quiet traffic hours around noon. However there will be a substantial number of days when wind conditions fluctuate near the border of the ellipse and controllers will be reluctant to relax separation standards temporarily. Also, pilots of light aircraft may refuse to accept reduced separation. On the other hand, after some experience, ATC may find that the preference of operating into wind could be changed to operating with cross-wind to take maximum advantage of the ability of cross-winds to move the wake vortex out of the safety corridor. If such policy is adopted the savings could be greater than the present calculations indicate.

The results of calculations of savings are sensitive to the price of fuel and the value of passenger time. In the aircraft operating costs used, fuel price constituted 50 per cent for airborne and 40 per cent for ground delays. The value of time assumed in these calculations accounted for 35 per cent of total airborne hourly cost and 47 per cent of ground delay hourly cost.

Ground delays are sometimes absorbed in time allowance for connections. On the other hand delays of one flight may cause delays of connecting flights, and have a snowball effect. The same is true for arrival delays. Delays may also require the availability of other aircraft to replace the late aircraft. Similarly, extended gate occupancy due to departure delays required additional gates. Such repercussions are not considered in this study, since these delays, when due to wake turbulence separation, will occur on calm days, when a wake vortex visualization system is not effective and the wind statistics show that the number of calm days will be large enough to warrant the availability of back up systems, and therefore no real savings can be claimed for times when they are not called upon.

Similarly, the number of days that capacity is increased due to reduced separation, will not be large enough to allow postponement of expansion of the runway system, required to maintain average delays at acceptable levels.

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2. TSC Wake Vortex Data Base and Applications, by James N. Hallock et al, U.S. Department of Transportation, Transportation Systems Center, Cambridge, Massachusetts, Proceedings of the Aircraft Wake Vortices Conference March 15-17, 1977, J.N. Hallock, Editor, June 1977.

3. Aircraft Wake Vortex Take-off Tests at Toronto International Airport by T. Sullivan et al, U.S. Department of Transportation, Research and Special Programs Administration, Transportation Systems Center, Cambridge, Massachusetts, February 1979.

4. Quarterly Aircraft Operating Costs and Statistics, First Quarter 1980, Avmark Inc.

5. 1975 General Aviation Activity Survey. U.S. Department of Transportation. Federal Aviation Administration, Office of Management Systems, Information and Statistics Division, September 1976.

6. Air Traffic Designators, Transport Canada, Air, TP-143, November 1980.

APPENDIX

TABLE A.1

ARRIVALS AND DEPARTURES AT TORONTO INTERNATIONAL AIRPORT

1991 SCHEDULE

BETWEEN 0600 HRS AND 0659 HRS

AIRCRAFT TYPE	NO. OF ARRIVALS	NO. OF DEPARTURES
B-747	0	0
DC-10	0	1
B-767	0	0
B-727	0	0
B-737	0	0
B-757	0	0
DC-9	0	1
DHC-7	0	0
TOTAL	0	2

BETWEEN 0700 HRS AND 0759 HRS

AIRCRAFT TYPE	NO. OF ARRIVALS	NO. OF DEPARTURES
B-747	1	1
DC-10	2	2
B-767	8	1
B-727	3	7
B-737	2	5
B-757	0	2
DC-9	0	3
DHC-7	2	1
TOTAL	18	22

BETWEEN 0800 HRS AND 0859 HRS

AIRCRAFT TYPE	NO. OF ARRIVALS	NO. OF DEPARTURES
B-747	0	0
DC-10	4	4
B-767	4	8
B-727	5	9
B-737	3	4
B-757	1	1
DC-9	2	2
DHC-7	1	2
TOTAL	20	30

BETWEEN 0900 HRS AND 0959 HRS

AIRCRAFT TYPE	NO. OF ARRIVALS	NO. OF DEPARTURES
B-747	0	1
DC-10	1	6
B-767	6	9
B-727	7	6
B-737	1	2
B-757	1	1
DC-9	2	1
DHC-7	2	1
TOTAL	20	27

BETWEEN 1000 HRS AND 1059 HRS

AIRCRAFT TYPE	NO. OF ARRIVALS	NO. OF DEPARTURES
B-747	0	0
DC-10	0	3
B-767	4	3
B-727	5	10
B-737	2	0
B-757	1	1
DC-9	2	3
DHC-7	0	0
TOTAL	14	20

BETWEEN 1100 HRS AND 1159 HRS

AIRCRAFT TYPE	NO. OF ARRIVALS	NO. OF DEPARTURES
B-747	0	0
DC-10	0	1
B-767	4	5
B-727	5	5
B-737	1	2
B-757	1	0
DC-9	1	2
DHC-7	1	1
TOTAL	13	16

Table A.1 – Arrivals and Departures (cont'd)

BETWEEN 1200 HRS AND 1259 HRS

AIRCRAFT TYPE	NO. OF ARRIVALS	NO. OF DEPARTURES
B-747	1	1
DC-10	2	0
B-767	4	2
B-727	6	6
B-737	2	2
B-757	1	1
DC-9	3	0
DHC-7	1	2
TOTAL	20	14

BETWEEN 1300 HRS AND 1359 HRS

AIRCRAFT TYPE	NO. OF ARRIVALS	NO. OF DEPARTURES
B-747	2	0
DC-10	1	0
B-767	2	3
B-727	7	5
B-737	2	1
B-757	0	1
DC-9	0	2
DHC-7	0	0
TOTAL	14	12

BETWEEN 1400 HRS AND 1459 HRS

AIRCRAFT TYPE	NO. OF ARRIVALS	NO. OF DEPARTURES
B-747	2	0
DC-10	4	2
B-767	2	3
B-727	4	8
B-737	2	2
B-757	1	0
DC-9	3	0
DHC-7	1	1
TOTAL	19	16

BETWEEN 1500 HRS AND 1559 HRS

AIRCRAFT TYPE	NO. OF ARRIVALS	NO. OF DEPARTURES
B-747	4	0
DC-10	4	3
B-767	3	1
B-727	5	7
B-737	3	1
B-757	2	1
DC-9	2	3
DHC-7	1	1
TOTAL	24	17

BETWEEN 1600 HRS AND 1659 HRS

AIRCRAFT TYPE	NO. OF ARRIVALS	NO. OF DEPARTURES
B-747	6	1
DC-10	2	1
B-767	6	2
B-727	6	7
B-737	2	3
B-757	1	2
DC-9	2	0
DHC-7	1	0
TOTAL	26	16

BETWEEN 1700 HRS AND 1759 HRS

AIRCRAFT TYPE	NO. OF ARRIVALS	NO. OF DEPARTURES
B-747	6	3
DC-10	4	2
B-767	6	8
B-727	7	6
B-737	1	2
B-757	0	1
DC-9	2	2
DHC-7	1	2
TOTAL	27	26

Table A.1 - Arrivals and Departures (cont'd)

BETWEEN 1800 HRS AND 1859 HRS

AIRCRAFT TYPE	NO. OF ARRIVALS	NO. OF DEPARTURES
B-747	1	3
DC-10	3	6
B-767	5	6
B-727	7	7
B-737	3	3
B-757	2	1
DC-9	2	2
DHC-7	2	1
TOTAL	25	29

BETWEEN 1900 HRS AND 1959 HRS

AIRCRAFT TYPE	NO. OF ARRIVALS	NO. OF DEPARTURES
B-747	1	6
DC-10	2	4
B-767	9	8
B-727	7	5
B-737	3	2
B-757	0	1
DC-9	1	2
DHC-7	1	1
TOTAL	24	29

BETWEEN 2000 HRS AND 2059 HRS

AIRCRAFT TYPE	NO. OF ARRIVALS	NO. OF DEPARTURES
B-747	0	5
DC-10	5	1
B-767	5	3
B-727	9	5
B-737	0	2
B-757	0	0
DC-9	1	1
DHC-7	1	2
TOTAL	21	19

BETWEEN 2100 HRS AND 2159 HRS

AIRCRAFT TYPE	NO. OF ARRIVALS	NO. OF DEPARTURES
B-747	1	2
DC-10	4	4
B-767	3	3
B-727	7	5
B-737	6	0
B-757	1	0
DC-9	1	0
DHC-7	1	0
TOTAL	24	14

BETWEEN 2200 HRS AND 2359 HRS

AIRCRAFT TYPE	NO. OF ARRIVALS	NO. OF DEPARTURES
B-747	0	0
DC-10	4	3
B-767	3	6
B-727	8	1
B-737	0	2
B-757	0	0
DC-9	0	1
DHC-7	1	2
TOTAL	16	15

BETWEEN 2300 HRS AND 2359 HRS

AIRCRAFT TYPE	NO. OF ARRIVALS	NO. OF DEPARTURES
B-747	0	1
DC-10	0	1
B-767	1	2
B-727	0	0
B-737	0	0
B-757	1	0
DC-9	2	1
DHC-7	0	0
TOTAL	4	5

TABLE A.2

TORONTO INTERNATIONAL AIRPORT

GENERAL AVIATION IFR MOVEMENTS

(July 24, 1980)

GMT	AIRCRAFT TYPE		ARRIVALS	DEPARTURES	RUNWAY					
					05L	05R	23L	23R	14	32
04-0500	PA 31	L		X					X	
	LR 25	M		X				X		
	BE 18	L		X						X
	C 310	L	X				X			
05-0600	C 402	L	X					X		
	C 337	L	X			X				
	C 401	L	X							X
06-0700	C 401	L		X					X	
07-0800	LR 24	M	X			X				
	PA 23	L	X						X	
08-0900	LR 35	M		X				X		
	SW 3	L	X			X				
09-1000	PA ZT	L		X				X		
10-1100	PA 28	L	X		X					
	C 310	L		X						X
	FFJ	M		X						X
11-1200	WW 23	M	X		X					
	G 159	M		X	X					
	G 73	L		X						X
	C 421	L		X						X
	BE 20	L		X						X
	HS 25	M		X						X
12-1300	HS 25	M	X		X					
	LR 25	M	X		X					
	SW 2	L		X						X
	DC 3	M		X						X
	SW 4	L		X						X
	BE 20	L		X						X
	G 2	M		X						X
	WW 23	M		X						X
	LR 25	M		X						X
	C 414	L		X						X
	PA ZP	L		X						X
	PA 28	L		X						X
13-1400	AC 21	M	X							99
	PA 31	L	X		X					
	L 329	M	X		X					
	AC 21	M		X						99
	HS 25	M		X						32
	PA 23	L		X						32
	C 401	L		X						32
14-1500	C 310	L	X		X					
	BE 90	L	X		X					
	C 500	L	X		X					
	N 265	M	X		X					
	PA YE	L	X		X					
	AC 6T	L	X			X				
	LR 35	M	X		X					
	C 441	L	X		X					
	L 329	M		X						X
15-1600	FFJ	M	X		X					
	C 310	L		X						X
	PA 31	L		X						X
16-1700	C 414	L	X		X					
	C 551	M		X						X
	LR 25	M		X						X
	AC 6T	L		X						X

Table A.2 - General Aviation IFR Movements (cont'd)

GMT	AIRCRAFT TYPE	ARRIVALS	DEPARTURES	RUNWAY					
				05L	05R	23L	23R	14	32
17-1800	G 2 M	X					X		
	LR 35 M		X				X		
	PA 20 L		X						X
	WG 20 L	X					X		
	G 2 M		X				X		
	C 310 L		X				X		
	PA 10 L		X				X		
18-1900	DH 6 L	X					X		
	BE 20 L	X					X		
	PA ZT L	X					X		
	PA YL L		X				X		
	G 2 M		X				X		
19-2000	AC 69 L	X					X		
	C 340 L		X				X		
	N 265 M		X				X		
	LR 25 M		X				X		
	BE 20 L		X				X		
	AC 21 M		X				X		
	PA 30 L	X					X		
	C 500 L		X				X		
20-2100	WW 24 M		X				X		
	C 551 M		X				X		
	C 310 L		X				X		
	LR 25 M	X					X		
	BE 55 L	X					X		
	DC 3 M	X					X		
	BE 20 L	X					X		
	AC 21 M	X					X		
	G 159 M		X				X		
	G 2 M		X				X		
	HS 25 M	X					X		
21-2200	N 265 M	X					X		
	C 500 L	X				X			
	LR 25 M	X					X		
	C 411 L		X				X		
	C 172 L		X						88
	LR 25 M		X				X		
	PA 20 L	X					X		
	BE 20 L	X					X		
	C 500 L	X					X		
	LR 24 M	X					X		
	AC 21 M	X					X		
	C 441 L		X				X		
	WW 23 M		X				X		
	C 310 L		X				X		
	HS 25 M		X				X		
	LR 25 M		X				X		
22-2300	PA 31 L		X				X		
	C 421 L	X					X		
	G 2 M	X					X		
	PA ZT L	X					X		
	PA 20 L	X					X		
	BE 20 L		X						
23-2400	L 329 M		X				X		
	PA 20 L		X				X		
	L 329 M	X					X		
	C 310 L	X					X		
	C 500 L	X					X		
	L 329 M	X					X		

Table A.2 - General Aviation IFR Movements (cont'd)

GMT	AIRCRAFT TYPE	ARRIVALS	DEPARTURES	RUNWAY					
				05L	05R	23L	23R	14	32
00-0100	C 182 L	X					X		
	C 421 L	X					X		
	BE 20 L	X					X		
	PA 20 L	X					X		
	LR 25 M	X					X		
	LR 24 M		X				X		
01-0200	LR 25 M	X						X	
	BE 58 L	X						X	
	PA 28 L		X					X	
	G 159 M	X						X	
	BE 20 L	X						X	
	PA 23 L	X						X	
	SW 4 L	X						X	
02-0300	FEJ M	X						X	
	BE 58 L		X				X		
	BE 20 L		X				X		
03-0400	G 159 M	X						X	
	SW 4 L		X				X		

TABLE A.3

TORONTO INTERNATIONAL AIRPORT

GENERAL AVIATION IFR MOVEMENTS

(July 30, 1980)

VMC

GMT.	AIRCRAFT TYPE	ARRIVALS	DEPARTURES	RUNWAY					
				05L	05R	23L	23R	14	32
10-1100	SW 4		X	X					
	C 402		X	X					
	G 2		X						X
11-1200	LR 25	X					X		
	L 329	X					X		
	PA 31	X					X		
	WW 23	X					X		
	BE 20		X				X		
	PAZP		X				X		
12-1300	AC 21		X				X		
	N 265	X					X		
	L 329	X					X		
	PA 31	X					X		
	PA 31		X				X		
	L 329		X				X		
	LR 35	X					X		
	C 421	X					X		
	BE 55		X				X		
	HS 25		X				X		
	WW 23		X				X		
	N 265		X				X		
13-1400	PA 23	X					X		
	L 329	X					X		
	C 340	X					X		
	LR 35	X					X		
	PA 31	X					X		
	C 310		X				X		
	BE 20	X					X		
	PA 23	X				X			
	LR 35	X					X		
	C 421	X					X		
	C 421		X				X		
	L 329		X				X		
	MO 20		X				X		
14-1500	L 329		X				X		
	LR 35	X					X		
	PA 30	X					X		
	G 2	X					X		
	PA 60		X				X		
	C 172		X				X		
	PAYE		X				X		
	PA ZT		X				X		
15-1600	L 329	X					X		
	N 265	X					X		
	PA ZT	X					X		
	PA 28	X					X		
	PA 23		X				X		
	L 329		X				X		
	C 172		X				X		
16-1700	PA 34	X					X		
	BE 55	X					X		
	C 320	X					X		
	C 340		X				X		
	BE 20		X				X		
	C 402		X				X		
	C 421		X				X		

Table A.3 - General Aviation IFR Movements (cont'd)

GMT	AIRCRAFT TYPE	ARRIVALS	DEPARTURES	RUNWAY					
				05L	05R	23L	23R	14	32
17-1800	PA 31	X					X		
	C 182		X				X		
	C 402		X				X		
	C 310	X					X		
	G 159		X				X		
	G 2		X				X		
	PA 30		X				X		
18-1900	N 265	X					X		
	LR 35		X				X		
	PA 23		X				X		
	LR 35		X				X		
	PA 32		X				X		
19-2000	FFJ	X					X		
	C 421	X					X		
	PA 23	X					X		
	PA 28		X				X		
	WW 23		X				X		
	LR 25		X				X		
	FFJ		X				X		
	N 265		X				X		
	BE 55	X					X		
	LR 35		X				X		
20-2100	HS 25		X				X		
	PA 31		X				X		
	FFJ		X				X		
	C 337	X					X		
	LR 35		X				X		
	PA 30		X				X		
	PA 31		X				X		
	BE 10		X				X		
	C 421		X				X		
21-2200	BE 10	X					X		
	G 2		X				X		
	PA 20		X				X		
	N 265	X					X		
	N 265		X				X		
	PAZP		X				X		
22-2300	WW 23	X					X		
	C 500	X					X		
	AC 69	X					X		
	C 421	X					X		
	G 2	X					X		
	PA 23		X				X		
	PAZP	X					X		
	HS 25	X					X		
	BE 55	X					X		
	L 329		X				X		
	AC 69		X				X		
	C 500		X				X		
	WW 23		X				X		
	HS 25	X					X		
23-2400	G 2	X					X		
	C 500	X					X		
	C 421		X				X		
	BE 20	X					X		
	PA 3T	X					X		
	SW 2	X					X		
	BE 36		X				X		

Table A.3 - General Aviation IFR Movements (cont'd)

GMT	AIRCRAFT TYPE	ARRIVALS	DEPARTURES	RUNWAY					
				05L	05R	23L	23R	14	32
00-0100	DA 10	X					X		
	LR 35		X				X		
	BS 25	X					X		
	PA 31	X					X		
	C 421	X					X		
	C 310		X				X		
	C 310		X				X		
	G 1		X				X		
	L 329	X					X		
01-0200	C 402	X		X					
	PA/T	X		X					
	BS 25	X		X					
	SW 4	X		X					
	DA 10		X						X
02-0300	BE 90	X		X					
	C 310	X		X					
	PA 31	X							X
	AC 21	X		X					
	L 329	X		X					
	C 402		X						X
	BE 90		X						28
	LR 25		X						X
03-0400	SW 4		X						X
	L 329		X						X

TABLE A.4

DAILY TFR MOVEMENTS

1979 to 1980

MONTH	MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY	SATURDAY	SUNDAY
March 1979	617	621	607	587	627	469	473
	546	566	599	601	639	500	485
	580	604	595	663	647	515	487
	620	589	613	596	596	512	560
				63[illegible]	603	540	
Total	2,363	2,380	2,414	3,086	3,112	2,536	2,005
April 1979	556	597	502	67[illegible]	428	543	526
	551	617	603	569	510	442	448
	565	605	575	61[illegible]	621	460	461
	624	633	681	725	643	543	509
	623						491
Total	2,919	2,452	2,361	2,578	2,202	1,988	2,435
May 1979		628	629	669	643	529	548
	590	602	685	648	643	499	483
	572	586	635	587	583	461	439
	473	540	599	627	666	511	484
	556	599	677	624			
Total	2,191	2,955	3,225	3,155	2,535	2,000	1,984
June 1979					623	484	477
	600	611	644	659	676	491	501
	613	572	631	632	623	466	526
	612	650	609	702	685	525	531
	596	649	659	701	683	539	
Total	2,421	2,482	2,543	2,694	3,290	2,505	2,035
July 1979							511
	546	591	553	631	636	507	522
	629	716	698	674	642	530	537
	595	587	630	663	662	504	529
	637	657	644	663	640	517	512
	581	626					
Total	2,988	3,177	2,525	2,631	2,580	2,058	2,611
August 1979			654	642	652	533	493
	510	646	671	615	621	509	530
	611	653	663	639	674	465	555
	571	620	646	666	708	510	516
	61[illegible]	665	667	652	633		
Total	2,310	2,584	3,301	3,214	3,288	2,017	2,094
September 1979						505	471
	501	578	669	665	658	534	512
	619	601	627	683	652	512	496
	587	586	624	617	636	467	499
	589	610	665	624	647	519	500
Total	2,296	2,375	2,585	2,589	2,593	2,537	2,478

Table A.4 - Daily IFR Movements (1979 to 1980) (cont'd)

MONTH	MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY	SATURDAY	SUNDAY
October 1979	566 518 570 563 597	671 603 625 636 615	682 668 679 677 625	689 625 664 673	684 631 693 618	497 615 497 465	462 378 516 480
Total	2,814	3,150	3,331	2,651	2,626	2,074	1,836
November 1979	532 554 521 608	631 620 647 637	636 599 610 625	687 672 676 547 632	619 633 661 534 638	459 466 500 443	446 482 548 520
Total	2,215	2,535	2,470	3,114	3,085	1,868	1,996
December 1979	611 546 564 423 454	612 577 614 307	630 633 597 442	677 655 699 515	655 651 675 521	478 454 473 426 463	496 458 460 433 415
Total	2,598	2,110	2,302	2,546	2,502	2,284	2,262
January 1980	553 583 587 556	381 586 565 584 580	542 647 606 605 600	603 638 657 630 613	646 574 666 607	476 448 460 442	492 462 490 478
Total	2,279	2,696	3,000	3,141	2,493	1,826	1,922
February 1980	569 585 545 599	591 613 581 653	632 643 643 658	603 646 668 656	589 583 660 515 622	447 451 475 509	478 490 463 502
Total	2,298	2,438	2,576	2,573	2,969	1,882	1,933
Grand Total	29,692	31,334	32,633	33,972	33,275	25,575	25,591
Average	571	603	628	641	628	492	492
Percentage	14	15	15.5	16	15.5	12	12

SOURCE: Monthly Reports of Aircraft Movements, Aviation Statistics Centre,
APS Analysis

TABLE A5.1

CONFIGURATION D WITH WT

SUMMARY OF AVERAGE DELAY BY HOUR (MINS)

TYPE	TOTAL	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	1	2
60.0 PERCENT DEMAND																									
ARR	.2	0.	0.	0.	0.	.4	.4	.5	.4	.5	.5	.2	.6	.7	.9	1.5	1.2	1.6	1.0	1.2	.4	0.	0.	.3	0.
DPT	1.5	0.	0.	0.	.1	.7	5.1	1.7	1.0	.5	.5	.6	.3	.9	1.2	2.5	1.8	2.3	.6	.5	.6	.1	0.	0.	0.
TTL	1.1	0.	0.	0.	.0	.6	3.3	1.1	.7	.5	.5	.5	.5	.8	1.1	2.0	1.5	1.9	.8	1.0	.5	.1	0.	.2	0.
70.0 PERCENT DEMAND																									
ARR	1.1	0.	0.	0.	0.	.5	.6	.7	.5	.5	.8	.4	.9	1.0	1.8	2.1	1.6	2.0	1.1	1.5	.6	0.	0.	.3	0.
DPT	2.8	0.	0.	0.	.1	1.2	9.1	7.4	1.9	.9	.5	.9	.5	.9	1.5	3.6	3.5	3.7	1.1	.7	.9	.1	0.	0.	0.
TTL	2.0	0.	0.	0.	.0	.9	5.8	4.2	1.2	.7	.7	.7	.7	1.0	1.7	2.9	2.5	2.9	1.1	1.2	.7	.1	0.	.2	0.
80.0 PERCENT DEMAND																									
ARR	1.6	0.	0.	0.	0.	.7	1.0	.9	.7	.5	.8	.7	1.0	1.3	2.3	3.6	3.1	3.0	1.3	2.3	.9	.1	0.	.2	0.
DPT	7.0	0.	0.	0.	.1	1.5	15.6	22.8	13.1	1.9	.7	1.3	.7	1.8	2.2	6.6	11.8	11.0	2.4	.7	1.1	.1	.2	0.	0.
TTL	4.3	0.	0.	0.	.0	1.1	10.1	12.3	7.1	1.3	.8	1.0	.9	1.5	2.2	5.1	7.2	7.1	1.8	1.7	1.0	.1	.1	.2	0.
90.0 PERCENT DEMAND																									
ARR	3.0	0.	0.	0.	0.	.8	1.5	1.3	.9	.5	1.0	1.0	1.1	2.3	4.3	5.5	7.1	8.1	3.2	3.1	1.6	.1	0.	.2	0.
DPT	14.8	0.	0.	0.	.1	3.3	20.7	35.8	32.2	18.2	2.6	1.9	.8	2.4	2.9	11.8	25.7	30.3	22.9	8.4	1.4	.2	.3	0.	0.
TTL	8.9	0.	0.	0.	.0	2.3	13.4	19.2	17.1	10.3	1.7	1.5	1.0	2.4	3.7	8.7	16.2	19.7	11.7	4.9	1.5	.1	.2	.2	0.

TABLE A5.2

CONFIGURATION D WITHOUT MT

SUMMARY OF AVERAGE DELAY BY HOUR (MINS)

TYPE	TOTAL	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	1	2
60.0 PERCENT DEMAND																									
ARR	.5	0.	0.	0.	0.	.2	.3	.3	.3	.3	.3	.2	.4	.5	.4	.8	.5	.9	.7	.7	.3	0.	0.	.3	0.
DPT	.8	0.	0.	0.	.1	.5	2.9	.8	.8	.3	.3	.5	.2	.7	.9	1.3	.7	1.1	.4	.4	.3	.0	0.	0.	0.
TTL	.7	0.	0.	0.	.0	.4	1.9	.6	.5	.3	.3	.4	.3	.6	.7	1.0	.6	1.0	.5	.6	.3	.0	0.	.2	0.
70.0 PERCENT DEMAND																									
ARR	.6	0.	0.	0.	0.	.3	.4	.4	.4	.3	.5	.2	.5	.7	.6	1.0	.8	1.2	.8	.9	.4	0.	0.	.3	0.
DPT	1.3	0.	0.	0.	.1	.8	4.8	1.3	1.2	.5	.4	.6	.3	.7	1.1	1.7	1.4	1.8	.5	.5	.5	.0	0.	0.	0.
TTL	1.0	0.	0.	0.	.0	.6	3.1	.9	.8	.4	.5	.5	.4	.7	.9	1.3	1.1	1.5	.7	.7	.4	.0	0.	.2	0.
80.0 PERCENT DEMAND																									
ARR	.8	0.	0.	0.	0.	.3	.6	.6	.6	.3	.5	.4	.6	.7	.8	1.9	1.2	1.4	.9	1.1	.4	.1	0.	.2	0.
DPT	2.6	0.	0.	0.	.1	1.0	9.8	6.2	1.9	.6	.5	1.0	.4	1.1	1.5	3.2	3.6	2.3	.7	.5	.6	.0	.1	0.	0.
TTL	1.7	0.	0.	0.	.0	.7	6.3	3.5	1.3	.5	.5	.7	.5	.9	1.1	2.6	2.3	1.9	.8	.9	.5	.1	.1	.2	0.
90.0 PERCENT DEMAND																									
ARR	1.1	0.	0.	0.	0.	.4	.8	.8	.7	.3	.6	.6	.7	1.0	1.4	2.4	1.7	2.1	1.1	1.5	.6	.1	0.	.2	0.
DPT	5.1	0.	0.	0.	.1	1.7	13.3	15.1	5.1	1.0	.7	1.4	.5	1.8	2.1	6.1	10.7	6.1	1.2	.6	.8	.0	.2	0.	0.
TTL	3.1	0.	0.	0.	.0	1.2	8.5	8.2	3.0	.7	.7	1.0	.6	1.4	1.7	4.3	6.1	4.2	1.1	1.2	.7	.1	.2	.2	0.

TABLE A5.3

CONFIGURATION E WITH WT *

SUMMARY OF AVERAGE DELAY BY HOUR (MINS)

TYPE	TOTAL	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	1	2
60.0 PERCENT DEMAND																									
ARR	.8	0.	0.	0.	0.	.4	.4	.5	.4	.5	.5	.2	.6	.7	.9	1.5	1.2	1.6	1.0	1.2	.4	0.	0.	.3	0.
DPT	2.2	0.	0.	0.	.1	.6	6.4	3.4	1.5	.8	.5	.7	.5	1.0	1.5	3.7	3.9	2.7	.9	.9	.6	.3	0.	0.	0.
TTL	1.5	0.	0.	0.	.1	.6	4.1	2.0	1.0	.7	.5	.5	.6	.9	1.1	2.6	2.5	2.2	.9	1.1	.5	.2	0.	.2	0.
70.0 PERCENT DEMAND																									
ARR	1.1	0.	0.	0.	0.	.5	.6	.7	.5	.5	.8	.4	.9	1.0	1.8	2.1	1.6	2.0	1.1	1.5	.6	0.	0.	.3	0.
DPT	5.2	0.	0.	0.	.1	1.5	11.0	14.9	6.6	1.8	.6	1.0	.6	1.1	2.1	5.8	11.4	8.9	2.0	1.5	1.4	.3	0.	0.	0.
TTL	3.2	0.	0.	0.	.1	1.1	7.0	8.1	3.7	1.2	.7	.7	.8	1.1	1.9	4.0	6.4	5.6	1.5	1.5	1.0	.1	0.	.2	0.
80.0 PERCENT DEMAND																									
ARR	1.3	0.	0.	0.	0.	.7	1.0	.9	.7	.5	.8	.7	1.0	1.3	2.3	3.6	3.1	3.0	1.3	2.3	.9	.1	0.	.2	0.
DPT	13.3	0.	0.	0.	.1	1.8	17.3	33.4	32.1	15.9	1.0	1.3	1.0	2.2	2.9	10.8	25.0	27.8	18.0	5.1	1.8	.3	.4	0.	0.
TTL	7.5	0.	0.	0.	.1	1.4	11.2	17.8	17.1	8.9	.9	1.0	1.0	1.8	2.6	7.2	13.6	15.9	8.4	3.2	1.3	.2	.3	.2	0.
90.0 PERCENT DEMAND																									
ARR	3.0	0.	0.	0.	0.	.8	1.5	1.3	.9	.5	1.0	1.0	1.1	2.3	4.3	5.5	7.1	8.1	3.2	3.1	1.6	.1	0.	.2	0.
DPT	26.9	0.	0.	0.	.1	3.7	24.5	51.5	57.1	44.5	22.4	6.3	1.0	3.2	4.2	17.6	42.9	52.9	52.1	-0.5	14.1	1.2	.4	0.	0.
TTL	14.9	0.	0.	0.	.1	2.5	15.8	27.3	29.9	25.1	10.4	3.7	1.1	2.8	4.3	11.6	24.6	31.5	24.2	15.6	8.1	.7	.3	.2	0.

TABLE A5.4

CONFIGURATION E WITHOUT WT *

SUMMARY OF AVERAGE DELAY BY HOUR (MINS)

TYPE	TOTAL	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	1	2
60.0 PERCENT DEMAND																									
ARR	.5	0.	0.	0.	0.	.2	.3	.3	.3	.3	.3	.2	.4	.5	.4	.8	.5	.9	.7	.7	.3	0.	0.	.3	0.
DPT	1.2	0.	0.	0.	.1	.7	3.6	1.2	1.2	.5	.4	.5	.3	.7	1.2	2.2	1.6	1.3	.6	.7	.4	.2	0.	0.	0.
TTL	.8	0.	0.	0.	.1	.5	2.4	.8	.8	.4	.3	.4	.4	.6	.8	1.5	1.1	1.1	.6	.7	.3	.1	0.	.2	0.
70.0 PERCENT DEMAND																									
ARR	.6	0.	0.	0.	0.	.3	.4	.4	.4	.3	.5	.2	.5	.7	.6	1.0	.8	1.2	.8	.9	.4	0.	0.	.3	0.
DPT	2.0	0.	0.	0.	.1	1.0	6.5	3.1	2.2	1.0	.4	.8	.4	.8	1.4	2.6	3.3	2.2	1.0	1.0	.9	.2	0.	0.	0.
TTL	1.3	0.	0.	0.	.1	.7	4.2	1.8	1.3	.7	.5	.6	.5	.7	1.0	1.8	2.0	1.7	.9	.9	.6	.1	0.	.2	0.
80.0 PERCENT DEMAND																									
ARR	.8	0.	0.	0.	0.	.3	.6	.5	.6	.3	.5	.4	.6	.7	.8	1.9	1.2	1.4	.9	1.1	.4	.1	0.	.2	0.
DPT	4.7	0.	0.	0.	.1	1.2	11.9	13.7	6.5	1.3	.5	1.1	.6	1.6	1.8	4.8	10.0	5.6	1.5	1.1	1.1	.2	.3	0.	0.
TTL	2.8	0.	0.	0.	.1	.8	7.6	7.4	3.7	.9	.5	.8	.6	1.2	1.2	3.4	5.4	3.6	1.1	1.1	.8	.1	.2	.2	0.
90.0 PERCENT DEMAND																									
ARR	1.1	0.	0.	0.	0.	.4	.8	.8	.7	.3	.6	.6	.7	1.0	1.4	2.4	1.7	2.1	1.1	1.5	.6	.1	0.	.2	0.
DPT	11.5	0.	0.	0.	.1	2.0	16.6	28.2	25.0	9.9	.5	2.2	.7	2.4	2.7	10.9	26.5	24.2	12.0	2.9	1.3	.1	.4	0.	0.
TTL	6.4	0.	0.	0.	.1	1.4	10.6	15.0	13.3	5.6	.7	1.4	.7	1.7	2.0	6.7	13.8	13.7	5.8	2.0	1.0	.1	.3	.2	0.

TABLE A5.5

CONFIGURATION F WITH WT *

SUMMARY OF AVERAGE DELAY BY HOUR (MINS)

TYPE	TOTAL	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	1	2
60.0 PERCENT DEMAND																									
APP	1.7	0.	0.	0.	0.	.4	.9	1.2	1.1	.8	1.0	.3	.9	.9	1.7	4.1	4.4	2.6	1.3	2.8	.9	0.	0.	.3	0.
DPT	.9	0.	0.	0.	0.	.6	1.7	1.4	.6	.2	.4	.4	.2	.9	1.0	1.3	1.0	1.8	.4	.4	.5	.1	0.	0.	0.
TTL	1.3	0.	0.	0.	0.	.5	1.4	1.3	.8	.5	.8	.3	.6	.9	1.4	2.7	2.8	2.2	.9	2.0	.7	.1	0.	.2	0.
70.0 PERCENT DEMAND																									
APP	3.6	.0	0.	0.	0.	.7	1.5	2.3	2.3	.8	1.3	.5	1.3	1.9	4.4	5.4	11.9	9.4	2.9	4.1	1.9	.1	0.	.4	0.
DPT	1.3	0.	0.	0.	0.	.8	2.6	2.2	.9	.4	.6	.5	.4	1.2	1.4	1.5	1.9	3.0	.9	.6	.9	.2	0.	0.	0.
TTL	2.5	.0	0.	0.	0.	.8	2.2	2.2	1.6	.6	1.0	.5	.8	1.5	3.1	3.4	7.1	6.1	2.0	2.9	1.4	.2	0.	.3	0.
80.0 PERCENT DEMAND																									
APP	11.6	.0	0.	0.	0.	.8	2.3	3.7	5.1	.8	1.3	.9	1.5	3.5	5.5	11.3	26.9	33.3	30.3	26.2	18.5	1.4	0.	.3	0.
DPT	1.9	0.	0.	0.	0.	1.0	4.3	3.1	1.3	.5	.6	.5	.6	1.6	1.7	2.3	3.2	4.1	1.1	.7	.8	.3	0.	0.	0.
TTL	6.8	.0	0.	0.	0.	1.0	3.6	3.4	3.1	.7	1.0	.7	1.1	2.7	3.8	6.8	15.6	18.1	17.9	17.7	9.3	.8	0.	.3	0.
90.0 PERCENT DEMAND																									
APP	25.6	.0	0.	0.	0.	1.0	4.1	6.7	10.0	1.6	1.5	1.3	1.7	5.3	12.1	24.7	47.9	59.8	63.7	67.5	65.2	31.9	2.2	.3	0.
DPT	3.2	0.	0.	0.	0.	1.5	6.4	8.6	1.8	.8	.9	.8	.6	2.3	2.0	3.7	4.4	6.3	2.0	.7	1.4	.9	.5	0.	0.
TTL	14.1	.0	0.	0.	0.	1.3	5.5	7.7	5.8	1.2	1.3	1.0	1.2	3.9	7.6	14.2	26.7	31.8	37.1	45.1	32.0	15.1	1.0	.3	0.

TABLE A5.6

CONFIGURATION: E WITHOUT

SUMMARY OF AVERAGE DELAY BY HOUR (MINS)

TYPE	TOTAL	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	1	2
60.0 PERCENT DEMAND																									
ARR	1.9	0.	0.	0.	0.	.2	.6	.7	.8	.5	.7	.2	.6	.7	.8	2.5	1.8	1.2	.8	1.6	.5	0.	0.	.3	0.
DPT	.6	0.	0.	0.	0.	.5	1.0	.8	.4	.1	.4	.3	.2	.9	.8	1.2	.7	.9	.3	.4	.3	.1	0.	0.	0.
TTL	.8	0.	0.	0.	0.	.5	.8	.8	.6	.3	.5	.3	.4	.8	.8	1.9	1.3	1.0	.6	1.2	.4	.1	0.	.2	0.
70.0 PERCENT DEMAND																									
ARR	1.5	.0	0.	0.	0.	.4	.7	1.2	1.5	.5	1.0	.3	.7	.9	1.3	3.0	3.7	1.8	1.2	2.6	.8	.1	0.	.4	0.
DPT	1.0	0.	0.	0.	0.	.8	1.4	1.2	.7	.4	.5	.4	.3	1.6	1.5	1.8	1.2	1.5	.5	.4	.6	.2	0.	0.	0.
TTL	1.2	.0	0.	0.	0.	.5	1.1	1.2	1.1	.4	.7	.4	.6	1.2	1.4	2.4	2.5	1.7	.9	1.9	.7	.1	0.	.3	0.
80.0 PERCENT DEMAND																									
ARR	3.0	.0	0.	0.	0.	.4	1.0	2.1	2.6	.5	.9	.5	.9	1.4	1.5	4.9	11.2	8.6	1.8	3.4	1.2	.5	0.	.3	0.
DPT	1.5	0.	0.	0.	0.	1.0	2.6	1.6	1.1	.5	.5	.5	.5	2.6	2.3	2.8	1.8	2.1	.7	.6	.9	.1	0.	0.	0.
TTL	2.3	.0	0.	0.	0.	.8	2.0	1.8	1.9	.5	.7	.5	.7	2.0	1.9	3.8	6.7	5.2	1.3	2.5	1.0	.3	0.	.3	0.
90.0 PERCENT DEMAND																									
ARR	5.3	.0	0.	0.	0.	.5	1.7	3.3	4.7	.6	1.0	.6	1.0	2.3	3.1	6.4	17.5	16.9	12.1	7.6	3.2	.5	0.	.3	0.
DPT	2.5	0.	0.	0.	0.	1.5	3.8	1.9	1.5	.5	1.1	.8	.6	3.6	4.2	6.8	4.4	2.4	.9	.6	1.1	.1	.2	0.	0.
TTL	4.2	.0	0.	0.	0.	1.3	3.0	2.6	3.0	.5	1.0	.8	.8	2.9	3.6	6.6	11.1	10.3	7.3	5.2	2.1	.3	.2	.2	0.

XVII

TABLE A6.1

CONFIGURATION D WITH WT

DEMAND TYPE	DEMAND TOTAL	RUNWAY ACTIVITY AND AVERAGE DELAY - (MINS) 14 OPS	14 DELAY	32 OPS	32 DELAY	5L OPS	5L DELAY	23R OPS	23R DELAY	5R OPS	5R DELAY	23L OPS	23L DELAY	EQUIPMENT TYPE DELAY - (MINS) HEAVY OPS	HEAVY DELAY	MEDIUM OPS	MEDIUM DELAY	LIGHT OPS	LIGHT DELAY
60.0 PERCENT DEMAND																			
ARR	384	0	0.	0	0.	51	.1	0	0.	333	.9	0	0.	129	.9	204	.9	51	.1
DPT	387	0	0.	387	1.5	0	0.	0	0.	0	0.	0	0.	129	1.5	205	1.5	53	1.4
TTL	771	0	0.	387	1.5	51	.1	0	0.	333	.9	0	0.	257	1.2	409	1.2	104	.8
70.0 PERCENT DEMAND																			
ARR	447	0	0.	0	0.	60	.1	0	0.	387	1.3	0	0.	150	1.2	237	1.3	60	.1
DPT	448	0	0.	448	2.6	0	0.	0	0.	0	0.	0	0.	148	3.1	240	2.7	60	2.4
TTL	895	0	0.	448	2.6	60	.1	0	0.	387	1.3	0	0.	299	2.2	477	2.0	119	1.2
80.0 PERCENT DEMAND																			
ARR	513	0	0.	0	0.	68	.1	0	0.	444	1.9	0	0.	172	1.8	273	1.9	68	.1
DPT	507	0	0.	507	7.0	0	0.	0	0.	0	0.	0	0.	168	8.3	273	6.7	66	4.9
TTL	1020	0	0.	507	7.0	68	.1	0	0.	444	1.9	0	0.	339	5.0	546	4.3	135	2.5
90.0 PERCENT DEMAND																			
ARR	571	0	0.	0	0.	75	.1	0	0.	496	3.4	0	0.	191	3.6	305	3.3	75	.1
DPT	570	0	0.	570	14.8	0	0.	0	0.	0	0.	0	0.	190	18.1	305	14.1	75	9.3
TTL	1141	0	0.	570	14.8	75	.1	0	0.	496	3.4	0	0.	381	10.8	610	8.7	150	4.7

TABLE A6.2

CONFIGURATION 'D WITHOUT WT

DEMAND TYPE	TOTAL	RUNWAY ACTIVITY AND AVERAGE DELAY - (MINS) 14 OPS	14 DELAY	32 OPS	32 DELAY	5L OPS	5L DELAY	23R OPS	23R DELAY	5R OPS	5R DELAY	23L OPS	23L DELAY	EQUIPMENT TYPE DELAY - (MINS) HEAVY OPS	HEAVY DELAY	MEDIUM OPS	MEDIUM DELAY	LIGHT OPS	LIGHT DELAY
60.0 PERCENT DEMAND																			
ARR	384	0	0.	0	0.	51	.1	0	0.	333	.5	0	0.	129	.6	204	.5	51	.1
DPT	387	0	0.	387	.8	0	0.	0	0.	0	0.	0	0.	129	.8	205	.9	53	.8
TTL	771	0	0.	387	.8	51	.1	0	0.	333	.5	0	0.	257	.7	409	.7	104	.4
70.0 PERCENT DEMAND																			
ARR	447	0	0.	0	0.	60	.1	0	0.	387	.7	0	0.	150	.7	237	.7	60	.1
DPT	448	0	0.	448	1.3	0	0.	0	0.	0	0.	0	0.	148	1.4	240	1.3	60	1.1
TTL	895	0	0.	448	1.3	60	.1	0	0.	387	.7	0	0.	299	1.1	477	1.0	119	.6
80.0 PERCENT DEMAND																			
ARR	513	0	0.	0	0.	68	.1	0	0.	444	.9	0	0.	172	1.0	273	.9	68	.1
DPT	507	0	0.	507	2.6	0	0.	0	0.	0	0.	0	0.	168	3.0	273	2.6	66	2.1
TTL	1020	0	0.	507	2.6	68	.1	0	0.	444	.9	0	0.	339	2.0	546	1.7	135	1.1
90.0 PERCENT DEMAND																			
ARR	571	0	0.	0	0.	75	.1	0	0.	496	1.3	0	0.	191	1.4	305	1.2	75	.1
DPT	570	0	0.	570	5.1	0	0.	0	0.	0	0.	0	0.	190	5.9	305	4.9	75	3.6
TTL	1141	0	0.	570	5.1	75	.1	0	0.	496	1.3	0	0.	381	3.7	610	3.1	150	1.9

TABLE A6.3

CONFIGURATION E WITH WT *

DEMAND TYPE	DEMAND TOTAL	RUNWAY ACTIVITY AND AVERAGE DELAY - (MINS) 14 OPS	14 DELAY	32 OPS	32 DELAY	5L OPS	5L DELAY	23R OPS	23R DELAY	5R OPS	5R DELAY	23L OPS	23L DELAY	EQUIPMENT TYPE DELAY - (MINS) HEAVY OPS	HEAVY DELAY	MEDIUM OPS	MEDIUM DELAY	LIGHT OPS	LIGHT DELAY
60.0 PERCENT DEMAND																			
ARR	384	0	0.	0	0.	0	0.	51	.1	0	0.	333	.9	129	.9	204	.9	51	.1
DPT	387	0	0.	0	0.	0	0.	387	2.2	0	0.	0	0.	129	2.3	205	2.2	53	1.9
TTL	771	0	0.	0	0.	0	0.	438	1.9	0	0.	333	.9	257	1.6	409	1.5	104	1.0
70.0 PERCENT DEMAND																			
ARR	447	0	0.	0	0.	0	0.	60	.1	0	0.	387	1.3	150	1.2	237	1.3	60	.1
DPT	448	0	0.	0	0.	0	0.	448	5.2	0	0.	0	0.	148	6.2	240	5.0	60	3.8
TTL	895	0	0.	0	0.	0	0.	508	4.6	0	0.	387	1.3	299	3.7	477	3.1	119	2.0
80.0 PERCENT DEMAND																			
ARR	513	0	0.	0	0.	0	0.	68	.1	0	0.	444	1.9	172	1.8	273	1.9	68	.1
DPT	507	0	0.	0	0.	0	0.	507	13.3	0	0.	0	0.	168	16.4	273	12.6	66	8.4
TTL	1020	0	0.	0	0.	0	0.	575	11.8	0	0.	444	1.9	339	9.1	546	7.3	135	4.2
90.0 PERCENT DEMAND																			
ARR	571	0	0.	0	0.	0	0.	75	.1	0	0.	496	3.4	191	3.6	305	3.3	75	.1
DPT	570	0	0.	0	0.	0	0.	570	26.9	0	0.	0	0.	190	33.1	305	25.5	75	16.9
TTL	1141	0	0.	0	0.	0	0.	645	23.8	0	0.	496	3.4	381	16.3	610	14.4	150	8.5

TABLE A6.4

CONFIGURATION E WITHOUT WT

DEMAND TYPE	TOTAL	RUNWAY ACTIVITY AND AVERAGE DELAY - (MINS)												EQUIPMENT TYPE DELAY - (MINS)					
		14		32		5L		23R		5R		23L		HEAVY		MEDIUM		LIGHT	
		OPS	DELAY	OPS	DELAY	OPS	DELAY	OPS	DELAY	OPS	DELAY	OPS	DELAY	OPS	DELAY	OPS	DELAY	OPS	DELAY
60.0 PERCENT DEMAND																			
ARR	384	0	0.	0	0.	0	0.	51	.1	0	0.	333	.5	129	.6	204	.5	51	.1
DPT	387	0	0.	0	0.	0	0.	387	1.2	0	0.	0	0.	129	1.2	205	1.3	53	1.0
TTL	771	0	0.	0	0.	0	0.	438	1.1	0	0.	333	.5	257	.9	409	.9	104	.6
70.0 PERCENT DEMAND																			
ARR	447	0	0.	0	0.	0	0.	60	.1	0	0.	387	.7	150	.7	237	.7	60	.1
DPT	448	0	0.	0	0.	0	0.	448	2.0	0	0.	0	0.	148	2.2	240	2.0	60	1.6
TTL	895	0	0.	0	0.	0	0.	508	1.8	0	0.	387	.7	299	1.5	477	1.3	119	.8
80.0 PERCENT DEMAND																			
ARR	513	0	0.	0	0.	0	0.	68	.1	0	0.	444	.9	172	1.0	273	.9	68	.1
DPT	507	0	0.	0	0.	0	0.	507	4.7	0	0.	0	0.	168	5.6	273	4.6	66	3.3
TTL	1020	0	0.	0	0.	0	0.	575	4.2	0	0.	444	.9	339	3.3	546	2.7	135	1.7
90.0 PERCENT DEMAND																			
ARR	571	0	0.	0	0.	0	0.	75	.1	0	0.	496	1.3	191	1.4	305	1.2	75	.1
DPT	570	0	0.	0	0.	0	0.	570	11.6	0	0.	0	0.	190	14.4	305	11.0	75	7.3
TTL	1141	0	0.	0	0.	0	0.	646	10.3	0	0.	496	1.3	381	7.9	610	6.1	150	3.7

TABLE A6.5

CONFIGURATION F WITH WT *

DEMAND TYPE	TOTAL	RUNWAY ACTIVITY AND AVERAGE DELAY - (MINS) 14 OPS	14 DELAY	32 OPS	32 DELAY	5L OPS	5L DELAY	23R OPS	23R DELAY	5R OPS	5R DELAY	23L OPS	23L DELAY	EQUIPMENT TYPE DELAY - (MINS) HEAVY OPS	HEAVY DELAY	MEDIUM OPS	MEDIUM DELAY	LIGHT OPS	LIGHT DELAY
60.0 PERCENT DEMAND																			
ARR	384	0	0.	0	0.	0	0.	384	1.7	0	0.	0	0.	129	1.6	204	1.8	51	1.8
DPT	387	0	0.	0	0.	0	0.	53	1.6	0	0.	334	.8	129	.8	205	.7	53	1.6
TTL	771	0	0.	0	0.	0	0.	437	1.7	0	0.	334	.8	257	1.2	409	1.3	104	1.7
70.0 PERCENT DEMAND																			
ARR	447	0	0.	0	0.	0	0.	447	3.6	0	0.	0	0.	150	3.6	237	3.7	60	3.4
DPT	448	0	0.	0	0.	0	0.	60	2.2	0	0.	388	1.2	148	1.4	240	1.1	60	2.2
TTL	895	0	0.	0	0.	0	0.	507	3.5	0	0.	388	1.2	299	2.5	477	2.4	119	2.8
80.0 PERCENT DEMAND																			
ARR	513	0	0.	0	0.	0	0.	513	11.6	0	0.	0	0.	172	11.8	273	11.8	68	10.6
DPT	507	0	0.	0	0.	0	0.	66	2.9	0	0.	441	1.8	168	2.0	273	1.6	66	2.9
TTL	1020	0	0.	0	0.	0	0.	579	10.6	0	0.	441	1.8	339	7.0	546	6.7	135	6.8
90.0 PERCENT DEMAND																			
ARR	571	0	0.	0	0.	0	0.	571	25.0	0	0.	0	0.	191	25.3	305	25.4	75	22.9
DPT	570	0	0.	0	0.	0	0.	75	4.3	0	0.	496	3.0	190	3.4	305	2.7	75	4.3
TTL	1141	0	0.	0	0.	0	0.	646	22.6	0	0.	496	3.0	381	14.4	610	14.0	150	13.7

TABLE A6.6

CONFIGURATION: F WITHOUT AT

DEMAND TYPE	TOTAL	14 OPS	14 DELAY	32 OPS	32 DELAY	5L OPS	5L DELAY	23R OPS	23R DELAY	5R OPS	5R DELAY	23L OPS	23L DELAY	HEAVY OPS	HEAVY DELAY	MEDIUM OPS	MEDIUM DELAY	LIGHT OPS	LIGHT DELAY
60.0 PERCENT DEMAND																			
ARR	384	0	0.	0	0.	0	0.	384	1.0	0	0.	0	0.	129	1.0	204	1.0	51	.9
DPT	387	0	0.	0	0.	0	0.	53	2.0	0	0.	334	.4	129	.5	205	.4	53	2.0
TTL	771	0	0.	0	0.	0	0.	437	1.1	0	0.	334	.4	257	.7	409	.7	104	1.4
70.0 PERCENT DEMAND																			
ARR	447	0	0.	0	0.	0	0.	447	1.5	0	0.	0	0.	150	1.5	237	1.5	60	1.3
DPT	448	0	0.	0	0.	0	0.	60	3.5	0	0.	388	.6	148	.7	240	.5	60	3.5
TTL	895	0	0.	0	0.	0	0.	507	1.7	0	0.	388	.6	299	1.1	477	1.0	119	2.4
80.0 PERCENT DEMAND																			
ARR	513	0	0.	0	0.	0	0.	513	3.0	0	0.	0	0.	172	3.0	273	3.1	68	2.8
DPT	507	0	0.	0	0.	0	0.	66	5.7	0	0.	441	.9	168	1.0	273	.8	66	5.7
TTL	1020	0	0.	0	0.	0	0.	579	3.3	0	0.	441	.9	339	2.0	546	1.9	135	4.2
90.0 PERCENT DEMAND																			
ARR	571	0	0.	0	0.	0	0.	571	5.8	0	0.	0	0.	191	6.0	305	5.9	75	6.3
DPT	570	0	0.	0	0.	0	0.	75	11.2	0	0.	496	1.2	180	1.3	305	1.1	75	11.2
TTL	1141	0	0.	0	0.	0	0.	646	6.5	0	0.	496	1.2	381	3.7	610	3.5	150	8.2

RELEASED - BECHTEL